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British Telecommunications Engineering

VOL 2 PART 2 JULY 1983

The Journal of
The Institution of British Telecommunications Engineers

BRITISH TELECOMMUNICATIONS ENGINEERING

VOL 2 PART 2 JULY 1983

Contents

Published in April, July, October and January by *British Telecommunications Engineering Journal,* 2–12 Gresham Street, London EC2V 7AG.
(Formerly *The Post Office Electrical Engineers' Journal* Vols. 1–74: April 1908–January 1982)
Price: 80p (£1·30 including postage and packaging). Orders by post only.

Annual subscription (including postage and packaging): home and overseas £5·20. (Canada and the USA $12·00).

Price to British Telecom and British Post Office staff: 48p.

ISSN 0262-401X

British Telecommunications Engineering

EDITORIAL

Although the British Telecommunications Act 1983 relaxed British Telecom's (BT's) monopoly of the supply of attachments, only approved equipment may be connected to the BT network. The British Approvals Board for Telecommunication (BATB) is an independent organisation appointed by the Government to test most types of telecommunications equipment against the standards set by the British Standards Institution (BSI). The tests ensure that the equipment is safe, is compatible with the BT network and that it meets the legal requirements for connection to it. An article in this issue of the *Journal* discusses the transmission performance aspects of the BSI standards for the simple extension telephone, one of the first items of equipment to be affected by the liberalisation policy. A second article describes TIGGER, an automatic test system for measuring the transmission performance of telephones. This equipment, designed by the British Telecom Research Laboratories, is a computer-based system that is capable of testing a telephone instrument against the appropriate standards.

This year is the fiftieth anniversary of the invention of polyethylene. The use of this material has had a major influence on the development of cables for telecommunications transmission systems throughout the world. An article on p. 81 of this issue of the *Journal* outlines briefly the history of the use of polyethylene in telecommunications, describes some of the problems encountered and shows how they were eventually overcome.

The fourth World Telecommunications Exhibition, TELECOM 83, the world's most prestigious international telecommunications exhibition, will be held in Geneva later this year. To mark this event, the next issue of the *Journal* will be a special edition containing articles, specially commissioned, on the equipment that will be on display in the British Pavilion.

Towards a Standard Measurable Telephone

Foreword

The following articles describe the background to the new British Standards for extension telephones and an automatic means of determining whether or not a particular telephone instrument meets these standards.

Many British Telecom (BT) personnel, drawing on a vast pool of experience of how the network functions, of the interface it currently offers, and how that interface is developing with advancing technology have contributed to the drafting of the standards. Joanna Crowe is a member of the team that has helped to make the British Standards Institution (BSI) standard a realistic and practical one. In the article which follows, she concentrates on the transmission aspects of the standard and gives some idea of the reasons why specific requirements are established and the thinking that has influenced the actual choice of specification levels.

Of course, standards are only of value if a means exists to test whether or not a telephone meets them. The second article by Harry Ward and Robin Cross describes TIGGER. TIGGER is an automatic telephone tester capable of assessing transmission performance against the BSI specification with very little operator involvement. Its development has tracked the evolution of the standard and, to a certain extent, influenced that evolution since the TIGGER designers were able to comment on the practicality of testing conformance with the standard. The article describes what TIGGER measures and how it does it.

Some people question BT's active involvement in the drafting of the BSI standards – believing that it is merely a means of encouraging competition with our own products. However, the involvement of these authors (and many others) have helped to ensure a reasonable standard—one that bars the connection of telephones which are too quiet or too loud for the network, for example—and a standard that is measurable. This is very important because, although BT no longer has a monopoly over the supply and maintenance of all telephones connected to the network, complaints regarding faint transmission etc. will still be addressed to BT.

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British Standard for Simple Extension Telephones: Transmission Aspects

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UDC 621.395.725.1:621.396

With the introduction of competitive supply of subscribers' apparatus, standards are being written for apparatus which is connected to the public switched telephone network. One of the first of these standards to be published is for simple extension telephones. This article explains the background to the transmission aspects of this standard.

INTRODUCTION

The British Telecommunications Act 1981 opened the way, subject to Government policy, for anybody to supply approved apparatus for connection to the public switched telephone network (PSTN) in the UK. This article is about the standards that approved extension telephones must meet.

Why are these standards needed?

National telephone networks are unique things. They are not just a collection of wires and switches; they are immensely complicated machines that function satisfactorily, on the whole, because throughout the network the impedances and return losses, the levels and the sensitivities, the cables and the telephones have all been designed to interwork. If a telephone that does not suit the network is connected, it is not only the owner of that telephone who is affected. Difficulty could be caused to other network users as well; for example, if the telephone concerned causes crosstalk. One of the purposes of having standards is to safeguard the intended operation of the network.

APPROVAL DOCUMENT

The legal standards for subscribers' apparatus are the

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approval documents issued by the Department of Industry (DoI) and approved by the Secretary of State. The British Standards Institution (BSI) has acted for the DoI in producing the necessary standards, which are then called up by the approval documents. Although the approval documents may call up the British Standards without alteration or exception, it is the approval documents that are the legal standard. Only approved apparatus may be connected to BT's networks. Approved apparatus must bear a green circle of approval when offered for sale. Unapproved apparatus must display a red triangle, which means that it is illegal to connect it to BT's network. Such apparatus can still be sold for export or for use on exclusively private systems.

The standards have been written by committees on which many interested parties are represented, including the DoI, British Telecom (BT), other network operators such as Kingston-upon-Hull Telephone Department and Cable and Wireless, various manufacturers' and suppliers' organisations (for example, the Independent Telecommunications Suppliers Association (ITSA) and the Telecommunications Engineering and Manufacturing Association (TEMA) etc.), users' associations (for example, Telecommunications Users Association), and the British Approvals Board for Telecommunications (BABT), which is the approvals authority.

This article considers just one product standard—the simple extension telephone standard. Some of the requirements (namely, most safety and some general network requirements that are common to several different types of network attachments) have been incorporated into 2 separate BSI documents. Hence the BSI specifications that are relevant to simple extension telephones are:

BS6301(1982) Specification for safety requirements for apparatus for connection to British Telecommunications networks.

BS6305(1982) Specification for general requirements for apparatus for connection to the British Telecommnications public switched telephone network.

BS6317(1982) Specification for simple extension telephones for connection to the British Telecommunications public switched telephone network.

Measurement methods are not discussed in this article, but descriptions of these can be found in the accompanying article[1] in this *Journal*. The standard at present applies only to telephone instruments supplied as extensions, with BT having supplied the prime instrument.

Simple Extension Telephone

The term *simple extension telephone* arose because at the time the standard was written BT was to retain the monopoly on supply of the prime instrument, and there are separate standards for facilities such as loudspeaking telephony. The expression *simple telephone* is defined in the standard as:

> 'Apparatus for non-loudspeaking voice communication over the PSTN for which initiation and termination of the call is under manual control and involves the mechanical lifting of a part or the whole of the apparatus. Where call signalling is provided it is made either by loop-disconnect signalling or multi-frequency signalling, with the signalling of each call being controlled by a rotary dial or a keypad, or by manual initiation of stored numbers.'

In practice, this means that the telephone has no special facilities which involve the PSTN, such as a monitor amplifier, although it could still include, say, a calculator or a time display.

TRANSMISSION REQUIREMENTS

The requirements discussed in this article cover not only the standard of transmission, but also network protection in the transmission mode; that is, in this context, 'transmission requirements' means 'requirements for the transmission state'. Hence, network protection requirements such as DC characteristics, limiting of signals sent to line, impedance balance about earth and signal power presented to the network above 3·4 kHz and the acoustic shock requirement, which is for safety, are included, as well as transmission-quality requirements such as loudness, frequency response, sidetone, noise, distortion, clipping, instability and impedance.

There are 2 general statements given in the standard that are relevant to the transmission characteristics to be discussed below.† These are that the requirements shall be met independently of line polarity and, unless otherwise stated, for all positions of a user-controlled receiving volume control, where fitted.

DC Characteristics

The mask, or set of limits, for the DC characteristics of the telephone instrument is shown in Fig. 1.

The upper limit of this mask ensures that the telephone can seize and hold the exchange line. At lower currents the limit is determined by the voltage available from a 50 V 400 Ω feed (that is, an exchange transmission bridge of the Stone type), which is predominant in the PSTN at present and by the OFF-HOOK detection threshold of System X. Also shown is the load line for the 50 V 400 Ω feeding arrangement, which is the practical limit on the current that will be fed to a telephone instrument. No requirement (other than DC characteristics) checks the performance beyond this load line or below 25 mA, which is normally sufficient current to seize and hold an exchange line.

The System X subscriber line interface units are required to provide a feeding current limited to a nominal value of 40 mA, with a maximum of 42 mA, for loop resistances up to 1000 Ω. The terminating equipment (in this case the telephone) must not be a constant current sink at or below 42 mA because this would be incompatible with the current feed. Therefore, from 33·5 mA, the upper limit of Fig. 1 follows the signalling-limit requirement[2] up to 42 mA. Beyond 42 mA the limit rises steeply, but prevents the telephone being a constant current sink below 45 mA.

In this standard, there are also lower limits on the voltage across the line terminals of the telephone. It is not desirable to have a DC short circuit connected to the feeding bridge, but this does not occur often because of the presence of the local line. The main reason for having a lower limit is to control regulation, but it also permits more than one telephone on a line working in parallel. Satisfactory parallel

† The transmission requirements appear in clauses 9 and 13 of BS6317 (1982). The general statements appear in clause 3 (General operating conditions).

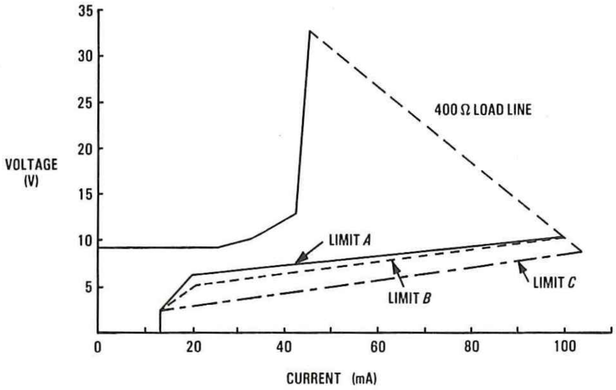


FIG. 1—DC characteristics

operation on a long line cannot be guaranteed but, if both telephones lie inside this mask, not all the current will be taken by one of them.

The long term lower limit is marked *A*. Limits *B* and *C* will be withdrawn from the standard in December 1987. This is to allow the suppliers to phase out present designs which do not meet *A*. Limit *C* is for carbon-microphone telephones only.

Impedance

The range of acceptable impedances for the telephone instrument is defined by specifying minimum return-loss values against a reference impedance. Return loss is given by the expression:

$$\text{Return Loss} = 20 \log_{10} \frac{|Z_b + Z_t|}{|Z_b - Z_t|}$$

where Z_b is the reference impedance and Z_t the measured impedance.

There are 2 reference impedances used. One of these, shown in Fig. 2, is a compromise impedance representative of local cables and, as it is being used for the exchange impedance for System X, this is the long-term target impedance for telephones. The other reference impedance is 600 Ω, but it is allowed only until 1987. This gives time for suppliers to change over to new models, and recognises the gradual build-up of System X equipment in the network over the next few years.

The requirement where the impedance of Fig. 2 is the reference is that the return loss shall be not less than 12 dB over the frequency range 200 Hz to 4 kHz and that the echo return loss shall be not less than 16 dB. The echo return loss is calculated using the CCITT† algorithm[3] over a frequency range of 300 Hz to 3·4 kHz. This applies for line currents of 25 mA to the maximum current which would be drawn from a 50 V 400 Ω source.

The 600 Ω requirement is similar. The limits are 12 dB and 16 dB as above, but for a frequency range of 300 Hz to 3·4 kHz and for line currents of 25 mA (the minimum line current used for testing) to 40 mA. Above 40 mA the requirement is less strict and follows the performance of present telephones with regulators. From 40 mA to the maximum current which would be drawn from a 50 V 400 Ω source, the real part of the impedance must be between 140 Ω and 1000 Ω and the modulus of the imaginary part must not exceed 350 Ω. (These numbers are a clarified version of the requirement which has been proposed. The original requirement included a return loss requirement of 4 dB, but the restraints on the real and imaginary parts make this unnecessary.)

Impedance control in the PSTN is a very important aspect of the design of the integrated digital network (IDN). In fact, it becomes more important with the new exchange designs than with the existing 2-wire exchanges. As the network adopts increasingly a 4-wire configuration, the telephone remains a 2-wire instrument. This means that there is a closed low-loss 4-wire loop directly facing the local network, where most impedance variation occurs, so stability becomes an important consideration.

The impedance variations in the local network arise because many gauges of cable are used (from 0·32 mm diameter copper cable to 2·5 mm diameter cadmium-copper open wire) and the impedance of the telephone varies with line current because of the regulator (from more than 600 Ω at low currents to about 150 Ω at high currents for the 746-type instrument). To reduce these variations, the intention is to restrict the gauges of cable used in the local network to a maximum gauge of 0·6 mm and to make the regulator ineffective by using a limited current feed. These precautions will make it possible to have a good match at the line card and so prevent instability in the 4-wire loop.

These precautions are basic network requirements. There is another performance-related consideration; this is that the 4-wire loop provides an echo path. If there is a bad match at one end, even if it does not make the loop unstable, it could make the connection very unpleasant for one party—and not the one with the bad telephone either. It could mean that BT will have to install echo-control devices in the inland network, an undesirable complication.

† CCITT—International Telegraph and Telephone Consultative Committee

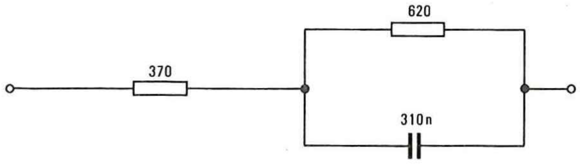


FIG. 2—Reference impedance

Earth Impedance Balance and Signal Balance About Earth

Earth impedance balance and signal balance about earth are network protection requirements. If the equipment is not balanced, it will cause crosstalk and interference (for example, mains hum) problems in the local network.

Signal Power Presented to the Network

The signal power presented to the network is also a network protection requirement. It ensures that, in the absence of acoustic input, the telephone does not send into the network out-of-band signals likely to upset the network.

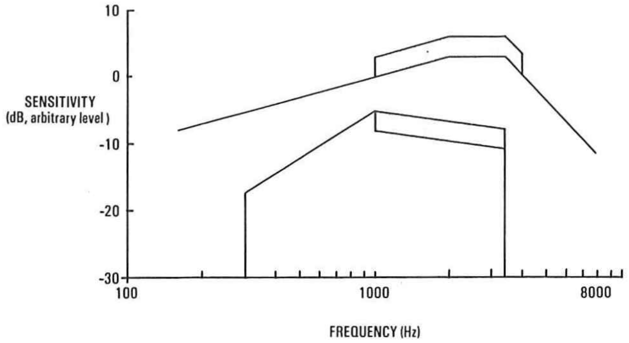
Sending-Sensitivity/Frequency Characteristics

The masks for the sending-sensitivity/frequency characteristics are shown in Fig. 3.

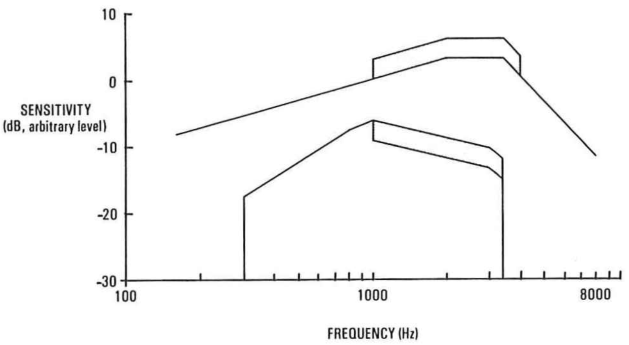
The general shape of these masks is a rising characteristic at low frequencies (up to 1 kHz) and a sharp cut-off at high frequencies (above 3·4 kHz). Although most of the power in speech is in the lower frequencies, the sharpness which makes it easy to understand (articulation) comes from the higher frequencies where the cable loss is greater. A rising characteristic emphasises the clarity of the speech without so much speech power being transmitted that the network is overloaded. The roll-off at low frequencies also reduces any mains hum picked up by the telephone, and the sharp cut-off at high frequencies is to avoid signals being transmitted that might interfere with an adjacent frequency band. The filters designed for frequency-division multiplex (FDM) and pulse-code modulation (PCM) circuits assume that the frequencies are already considerably attenuated above 3·4 kHz.

The mask is given for 3 ranges of line length and is measured for a complete local telephone system (LTS=telephone+line+feeding bridge+600 Ω termination on junction side of feeding bridge; see reference 1). The masks for longer line lengths are adjusted for the attenuation/frequency distortion of the cable used for measurements. The 3 masks control the spectrum seen at the exchange whatever the line length, which ensures that any non-linearity in the telephone (for example, the regulator) does not adversely affect the frequency response.

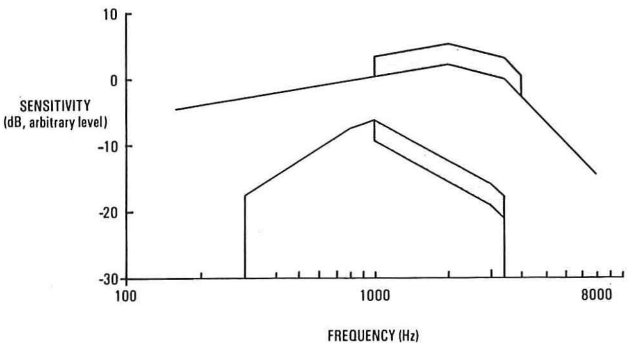
All the masks are given at an arbitrary level. The level is fixed by the value of the loudness rating, discussed below; the masks are intended solely to control the shape. Some transducers, however, have resonances that extend outside the frequency mask given. Therefore, until 1987, the response



(*a*) Zero line length

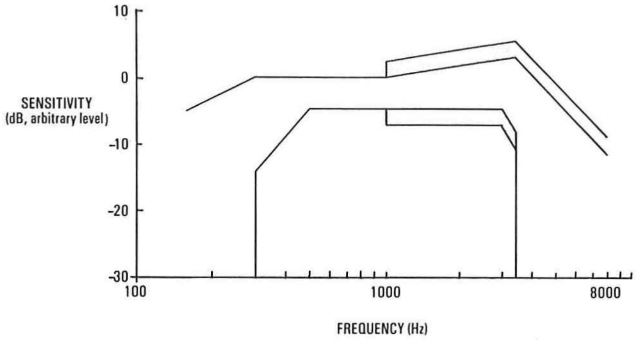


(*b*) Line lengths >0·0 km to ⩾3·0 km

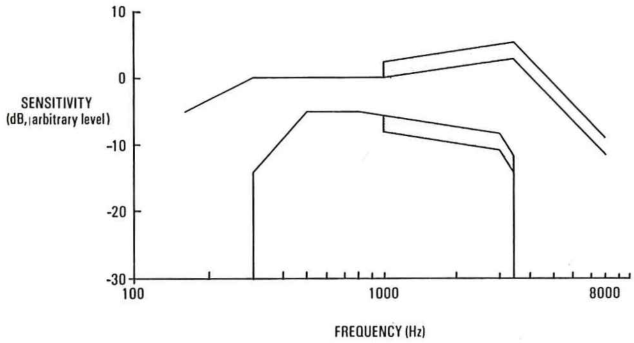


(*c*) Line lengths >3·0 km to ⩾7·5 km

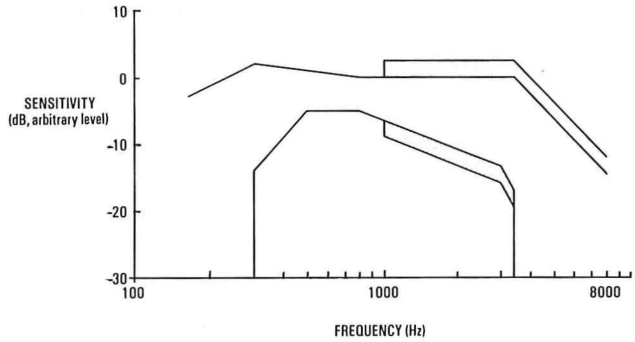
FIG. 3—Sending sensitivity



(*a*) Zero line length



(*b*) Line lengths >0·0 km to ⩾3·0 km



(*c*) Line lengths >3·0 km to ⩾7·5 km

FIG. 4—Receiving sensitivity

is allowed to go into one or other of the shaded boxes on each figure, but not into both. This is to allow manufacturers time to phase out old models.

Receiving-Sensitivity/Frequency Characteristics

The masks for the receiving-sensitivity/frequency characteristics are shown in Fig. 4.

As with the sending sensitivity/frequency characteristics, the masks are at an arbitrary level and there is a time-limited relaxation shown as shaded boxes.

The basic shape of the response is flat from 300 Hz to 3·4 kHz. When taken in conjunction with the sending and network responses, this is the desired shape. A corner has been cut off the lower limit of the mask from 300 Hz to 500 Hz because many telephones, particularly those made for overseas markets, use this cut-off as a hum filter. Some cut-off is desirable in order to reduce hum, but it cannot be too sharp since the absence of the low frequencies increases difficulty on quieter calls.

There is a sharp high-frequency cut-off similar to that of the sending characteristic, but with an additional requirement for controlling the sensitivity at 8 kHz. This is because 8 kHz is the sampling frequency normally used for digital systems in the PSTN. All codecs put onto the line some signal at the sampling frequency, whose level should not exceed −50 dBm0[4]. To prevent this signal interfering with conversation it must be considerably attenuated. The absolute sensitivity of −20 dBPa/V does not guarantee that the signal would be inaudible on short lines, but it should prevent it being annoying to most users.

Sending and Receiving Loudness Ratings

The masks for the sending and the receiving loudness ratings are shown in Figs. 5 and 6.

A loudness rating is a standardised measure of the transmission loss of a speech path. It is single-valued and is related to the loudness with which a listener perceives speech that has been emitted by a talker at a constant defined level. Loudness rating is measured by inserting attenua-

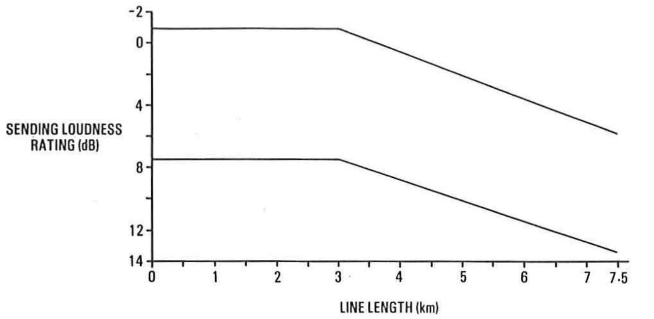


FIG. 5—Sending loudness rating mask

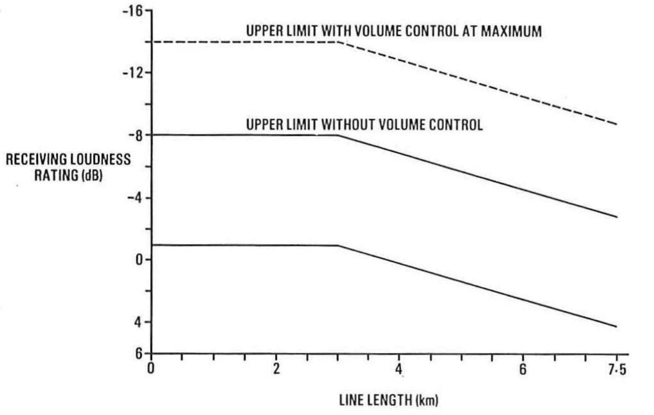


FIG. 6—Receiving loudness rating mask

tion/amplification in the test path until it is of equal loudness with the reference path. Attenuation is put into the reference path to obtain the required speech level, and the loudness rating is defined as the difference between the reference-path attenuation and the test-path attenuation. The sign convention means that a negative loudness rating implies that the test path is louder than the reference path and that a positive loudness rating means that the test path is quieter than the reference path.

Loudness ratings are used here to fix the absolute levels of the sensitivity/frequency characteristics. This does not mean that a knowledge of the loudness can be used to fix the sensitivity/frequency mask for all telephones, because the actual sensitivities depend on the frequency response of the telephone.

There are various constraints on the loudness of the telephones used on the network. These have been put together in a number of telephone specifications that have been written over the last few years. The masks take into consideration these specifications and the performance of current telephone sets.

The BT network transmission plan gives maximum (quietest) limits for the local-end loudness ratings that are based on the division of losses in the network to ensure that CCITT recommendations for international calls can be met. Meeting these recommendations ensures the quality of international calls, which now account for a significant slice of BT's revenue.

There are also minimum loss (loudest) constraints. These arise from considering the overload levels of the PSTN (for codecs, amplifiers etc.), minimum ratings for the network in international calls for the echo-control devices to work adequately, and crosstalk.

Carbon microphones are subjected to an additional test to check for excessive packing of the granules. Normally, when a carbon microphone is measured, it is first conditioned[1]. The purpose of this conditioning is to shake up the granules as they would be in normal use by the action of picking up and replacing the handset. Once the carbon granules have become packed, the microphone is less sensitive and very noisy. This test is to check that this packing does not happen too quickly otherwise the telephone could be unusable even if it passed all the tests with flying colours. The sensitivity is measured after conditioning in the normal way. The microphone is left undisturbed for 10 minutes with the current flowing and is then remeasured without being conditioned. The drop in sensitivity must be less than 6 dB.

The receiving loudness rating requirements include an extra requirement to cover telephones with user-controlled volume controls. The general statement that the requirements must be met for all settings of the control is not sensible in this case because the idea of a volume control is to exceed the mask. However, the telephone cannot be allowed to be too sensitive or an unacceptable amount of crosstalk will be intelligible; so the maximum setting of the control cannot be more than 6 dB above the mask. There is no limit for the quieter side—it can be switched off if desired, as long as no other parameter is upset. It should be noted that amplified handsets for the hard of hearing do not come under this standard as the 6 dB amplification would not be sufficient; these handsets are to be specified separately. In addition, it is specified that there must be some setting of the volume control for which the mask limits are met. This is to protect other users since, if the user with the volume control always hears incoming speech at the wrong level, he will talk at the wrong level and cause difficulty to the other party in the conversation.

Sidetone

Only a too-loud limit has been given for sidetone. Too-quiet sidetone is rarely a problem although it is desirable, from the network point of view, to have some sidetone because this controls the vocal levels into the network. There is also some indication that users prefer to have some sidetone, but this is not conclusive[5].

The ideal case would be to have a masked sidetone loudness rating (STMR) greater than 7 dB all the time, but as this is very difficult to achieve, there is some relaxation allowed. Louder sidetone can be tolerated if the connection is also loud and the requirement given below, relating the STMR and the sending loudness rating, is an empirical formula that has been found to be appropriate.

The requirement is that the STMR shall be numerically greater than:

(*a*) 7 dB, or

(*b*) the sending loudness rating for that line length plus 1·5 dB,

whichever is less. This applies for line lengths from 0·5 km to 7·5 km.

Only the overall level of sidetone has been specified. The frequency response of the sidetone path is immensely variable and, while it is not unimportant, the level has been controlled to the point where a wide range of responses are acceptable.

If a volume control is fitted, the STMR is allowed to be less than this limit by the same amount as the receiving loudness rating exceeds the mask for telephones without a control. This is because the volume control must be assumed to affect the sidetone path as well, and its effect is not as bad if the level of received speech in the ear also rises. In fact, this could be beneficial because, if the sidetone becomes loud, the user is less likely to wish to turn up the volume control too far.

Distortion

Distortion is specified for 2 reasons: its subjective effect on transmission performance and to control out-of-band products. Only the third harmonic is specified. It is the most

likely harmonic in the receiving path, and in the sending and sidetone paths, the even harmonics produced by carbon microphones can be very high before they have a significant effect on customer opinions. Control of the third harmonic, therefore, coupled with control of the frequency response, means that higher harmonics are not likely to be a problem.

Distortion is specified separately for sending, receiving and sidetone, since different levels can be tolerated on these paths. The requirements are 5%, 6% and 10% third harmonic respectively.

For sidetone, a level is quoted as well as a percentage, because if the sidetone loss is high, it could be little more than distortion products that reach the receiver, but at a level low enough to be unnoticeable to the user.

Clipping

Clipping is specified for sending and receiving. To automate the testing, clipping is defined as the third harmonic being greater than 10%.

Speech signals require a margin of about 15 dB between peak and RMS levels. The effect of reducing this margin is the degradation of transmission quality in terms of loudness and distortion.

The signal from the telephone is peak-limited by the network. If the telephone also clips the signal it will be quieter, distorted and noisy, particularly when digital systems such as PCM, which use companding, are involved (because the quantisation noise will rise). The telephone must be capable of sending out unclipped signals up to a level of 3·5 V peak-to-peak.

The receiving requirement prevents the telephone from significantly distorting speech signals in normal use. The telephone should not clip the signal until the sound pressure in the artificial ear is +10 dBPa.

Noise

Noise performance is specified for both sending and receiving. The need for a sending requirement is obvious and there are international recommendations[6,7] that govern the noise levels in the PSTN. The need for a receiving requirement is perhaps less obvious, but the effects of noise are cumulative. Both sending and receiving noise mask the speech signal and add to the noise reaching the user's ear through the sidetone path. This affects his listening effort and his vocal level, thus making conversation more difficult. It should be remembered that telephony means communication, so the receiving requirement does protect other network users as well.

The noise levels are referred to the line terminals of the telephone instrument. For sending, the telephone is placed in a quiet environment and the noise across a 600 Ω termination is measured. The idle noise, which is what this measures, is the determining factor in the effect on customer opinion of the noise in a telephony channel. Carbon microphones in good condition, measured like this, will pass the test with no problem. It is integrated circuit noise from electronic circuits in telephones that is the problem.

The receiving noise is also referred to the line terminals by the way it is specified. Hence, it is not necessary to break into the telephone circuitry at all and the noise level is compared with an equivalent received noise. The measurement, described in reference 1, compares the noise level in the ear produced by the telephone alone and with a noise input.

This noise requirement contains a time-limited clause. Until 1987, both sending and receiving requirements are −62 dBmp. This is higher than is recommended by international recommendations[6,7]—the long-term requirement is for −70 dBmp for sending and −65 dBmp for receiving.

Instability

The network can provide a wide range of terminations for the telephone and this can cause stability problems. These problems are more likely to arise with an electronic telephone using a linear microphone than with a carbon microphone telephone.

The stability requirement for the telephone is that there shall be no acoustic instability under a variety of feeding conditions with the acoustic transducers (handset or separate mouthpiece and earpiece as for the Candlestick telephone) placed in various positions such as near the case or near a hard reflecting surface.

The terminations used in the test are suitable for the transmission process representing the range of likely terminations at the local exchange. During call set-up other terminations can appear. The effect of these is controlled in the next requirement (acoustic shock) since it is not strictly a performance criterion.

The test used cannot hope to completely check a telephone under normal operating conditions. However, it should prove demanding enough that a telephone that satisfies this requirement will not generally give trouble in normal use.

Acoustic Shock

The requirement for acoustic shock is that the telephone shall not be capable of producing sound pressures in the user's ear large enough to damage hearing for any electrical or acoustic stimulus. The maximum allowed sound level is +24 dBPa (unweighted, RMS) in the artificial ear.

The test is in 2 parts: electrical and acoustical stimuli. The electrical stimulus, which is a large voltage applied at the line terminals, checks that there is a limiter in the telephone circuit. However, it does not check that the limiter is placed so that it will also limit signals in the sidetone path. If it does not, the sound pressure will not be limited in the case of instability. The acoustic stimulus uses a large sound pressure from the artificial mouth, using the line terminations that are not used in the instability test. These are 25 Ω and a very high resistance, which are conditions that can appear during call set-up, but not once the call is established. Under these conditions the sidetone is likely to be loud (hence the tendency to instability) and so this test checks that the limiter operates on the sidetone path.

Limits of Signals Sent to Line

To avoid excessively overloading and damaging the network it is necessary to put an upper limit on the signal that can be sent to line by the telephone instrument. This is set at +10 dBV. A pure-tone acoustic signal is used, but the measurement is made wideband because the signal will be severely clipped at these signal levels.

DISCUSSION

The British Standard for simple extension telephones is an attempt to specify the objective characteristics of telephones so as to be reasonably certain that any telephone which meets the requirements will perform satisfactorily when plugged into the customer's line. However, a telephone instrument is a man–machine interface. It is feasible that a telephone could pass all the requirements given in BS6317 and yet be unusable because no mention is made of subjective factors.

It would not be sufficient to design a telephone only to the requirements of BS6317. For example, the design of the handset is crucial to the performance of a telephone. There are a number of factors to be taken into account for this. The shape of the human head and the relative position of the mouth and ears are determining factors, together with considerations of how the handset is to be held, which involve the case design because this determines how the handset is picked up. If the handset cannot be comfortably held up against the ear or the shape of the earcap prevents it sealing well to the ear, there will be a considerable coupling loss

and the effective loudness of the telephone receiving path is reduced.

Linked with this effect is the leakage of environmental noise under the earcap, which would reduce the effective loudness even further. There are 2 principal paths for environmental noise to reach the ear. One is the leakage path already mentioned. The other is the noise picked up by the microphone, which reaches the ear via the sidetone path. Both the microphone and the handset shape affect this. The noise picked up by the microphone also results in increased noise being transmitted to the far-end user and, if the handset shape is wrong, the effective sensitivity to speech could be lower than is indicated by the sending-sensitivity measurements above, resulting in increased difficulty in conversing.

The requirements of this standard are for minimum acceptable performance to be compatible with the PSTN. A telephone that meets them is not necessarily a good telephone. For example, the sharp low-frequency cut-off in the receiving-sensivity/frequency characteristic accommodates a wider range of telephone models, but can have a significant and detrimental effect on customer opinion and difficulty.

CONCLUSION

This article has explained the reasoning behind the transmission requirements in the British Standard for simple extension telephones. The standard specifies only the objective characteristics of telephones. No mention is made of subjective factors, so it cannot be assumed that a telephone which meets BS6317 is a good telephone. It is important to realise that BS6317 does not give sufficient information for designing a telephone.

ACKNOWLEDGEMENTS

The author wishes to thank her colleagues, particularly in the Assessment Methods and the Electro-Acoustics Groups of British Telecom Research Laboratories, and Mr. G. Cook of BT's National and International Transmission Standards Group, for their help in preparing inputs to the British Standards committees.

References

1 Ward, H. F., and Cross, R. C. TIGGER—An Automatic Test System for measuring the Transmission Performance of Telephones. *Br. Telecommun. Eng.*, July 1983, **2**, p.70.

2 British Telecom Requirement 1151. Signalling on the Subscriber's Network.

3 CCITT. Influence of National Networks on Stability and Echo Losses in National Systems. Yellow Book Fascicle **III**.1, 1981, Recommendation G122.

4 CCITT. Performance Characteristics of PCM Channels at Audio Frequencies. Yellow Book Fascicle **III**.3, 1981, Recommendation G712.

5 Coleman, A. E. Sidetone and its Effect on Customer Satisfaction. *Br. Telecommun. Eng.*, Apr. 1982, **1**, p.10.

6 CCITT. Hypothetical Reference Connections. Yellow Book Fascicle **III**.1, 1981, Recommendation G103.

7 CCITT. Circuit Noise in National Networks. Yellow Book Fascicle **III**.1, 1981, Recommendation G123.

TIGGER—An Automatic Test System for Measuring the Transmission Performance of Telephones

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UDC 621.395:621.396.218:681.31

A computer-based system, for testing the transmission performance of telephone instruments to the British Standard (BS 6305 and BS 6317) is described, together with performance details and other possible uses. The system is called TIGGER and is an assembly of proprietary transmission measuring and test instruments linked together by BT designed hardware and software.

INTRODUCTION

In 1981, the British Government passed the British Telecommunications Act (1981) which amongst other items, liberalised the provision of extension telephones. This meant that British Telecom's (BT's) monopoly on the supply and maintenance of these instruments was abolished and the market opened up to other suppliers to sell approved instruments direct to the general public for connection to the public switched telephone network (PSTN).

Various tests needed to be performed on these telephone instruments to assess their suitability for approval. As part of this approvals test procedure the transmission-performance test equipment described here was developed.

Because of the short timescale for the introduction of liberalisation, readily-available laboratory test equipment was used wherever possible, the main effort being concentrated on the design and construction of a hardware unit containing the special test networks and current-feeding arrangements called for in the British Standards, together with the appropriate software for the controller.

The design of this equipment owes a great deal to previous work that had been done on objective performance measurement. Several computer-based test equipments for telephones have been developed over the years at British Telecom Research Laboratories (BTRL). The experience gained from this work was unique in the UK, and without it the liberalisation of attachments to the PSTN would not have been able to proceed as quickly as it has.

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The remainder of this article describes TIGGER and the tests that it performs in some detail.

TRANSMISSION PERFORMANCE TESTS

The transmission aspects of the tests are described elsewhere in this issue of the *Journal* [1].

The system has 2 main categories of test: those using the local telephone system arrangement (see Fig. 1) and those in the constant-current feed mode (see Fig. 2).

Throughout these tests (with the exception of the stability test) where the mouthpiece of the telephone is fixed relative to the earpiece, the handset is placed in the loudness rating guarding position (LRGP)[2], but where the mouthpiece is not fixed relative to the earpiece, the front plane of the mouthpiece is mounted 15 mm in front of the lip-ring (of the artificial mouth) and coaxial with the axis of the artificial mouth. In both cases the earpiece is sealed to the knife edge of the artificial ear.

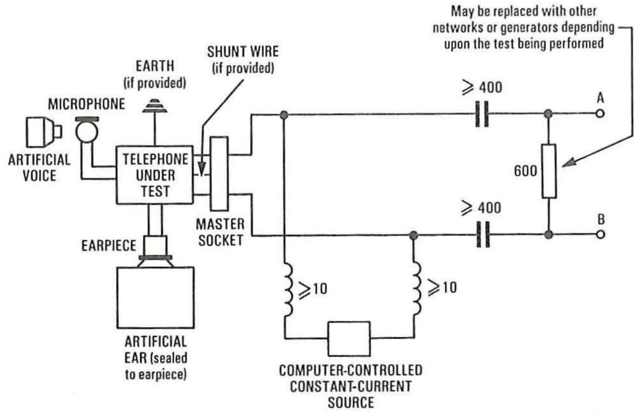


FIG. 2—Constant current feeding arrangement

Local Telephone System Tests

For this series of tests the circuit configuration of Fig. 1 is set up by the controller.

Sending Sensitivity

The sending sensitivity (S_{mj}), defined as

$$S_{mj} = \frac{\text{voltage at the } 600\,\Omega \text{ junction}}{\text{sound pressure at mouth reference point}} \text{ dBV/Pa},$$

is determined for various lengths of artificial line. The voltage at the 600 Ω point is measured at the fundamental frequency of the stimulus from the artificial mouth. Frequencies at third-octave intervals[3] from 200 Hz to 4000 Hz are used and the highest sensitivity from each of the 3 sound pressures is recorded. This method (upper-envelope method[4]) is used in order to take account of non-linear components in the characteristics of the telephone.

If the telephone has a carbon microphone, then conditioning is performed at each change of line length. The conditioning process is described in Appendix 1. In addition, a packing test is carried out at the 2·0 km line length (that is, the 2·0 km sensitivities are measured twice, once with conditioning and once, after a 10 minute wait with the microphone energised, without further conditioning).

In order to provide more detailed information, an additional test, at twelfth-octave frequency steps[3] is performed at 0·0 km.

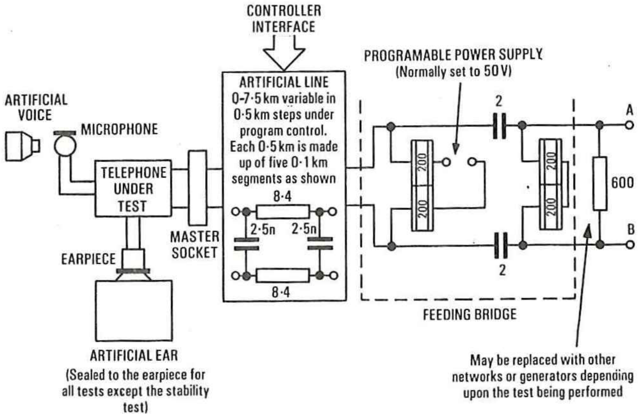


FIG. 1—Local telephone system arrangement

Receiving Sensitivity

The receiving sensitivity (S_{je}), defined as

$$S_{je} = \frac{\text{sound pressure in artificial ear}}{\frac{1}{2}\text{ junction EMF}} \text{ dBPa/V},$$

is determined for the same artificial line lengths and frequencies as the sending sensitivity. The sound pressure is measured at the fundamental frequency of the generator EMF.

Sidetone Sensitivity

The sidetone sensitivity (S_{mest}), defined as

$$S_{mest} = 20 \log_{10} \frac{\text{sound pressure in artificial ear}}{\text{sound pressure at mouth reference point}} \text{ dB},$$

is determined for the same artificial line lengths and frequencies as the sending sensitivity. The sound pressure in the artificial ear is measured at the fundamental of the artificial-mouth drive frequency. These sensitivities are used to calculate sidetone loudness rating only and are not output or stored since they are not required for the British Standard.

Sending, Receiving and Sidetone Loudness Ratings

The sending loudness rating (SLR) and receiving loudness rating (RLR) are calculated for each of the line lengths by using the algorithm defined in the British Standard[5]. The sidetone loudness rating (STMR) is calculated for all line lengths except 0·0 km, again by using the appropriate algorithm from the British Standard.

In this context a loudness rating is a number, derived from a weighted average of the appropriate objective sensitivities, which may be used as an indication of the relative loudness which would be perceived by the user.

Distortion Tests

The third harmonic distortion of the telephone in the SENDING, RECEIVING and SIDETONE modes is measured at various frequencies and line lengths. In the sending and sidetone cases the distortion is only measured when the artificial mouth is producing −5 dBPa at the mouth reference point.

Instability Test

The instability test is the one test of the whole series of transmission tests that requires some manual intervention. This is because this test is dependent upon the physical shape of the telephone being presented for approval.

The test is designed to ascertain whether the telephone will howl under certain conditions of termination and current feed (that is, the loop gain from microphone to earphone is greater than one). This is described more fully elsewhere[1].

The test circuit of Fig. 1 is set up by the controller with the line length set to 0·0 km. The system operator is instructed to establish whether there is any sustained audible oscillation with the 600 Ω resistor replaced by a 200 or a 1200 Ω resistor and with the power supply either delivering 50 V or 40 mA.

For handset-type telephones (that is, those with the microphone and earphone fixed relative to each other) the tests are carried out in free air, near the telephone case and in an artificial test corner, which is provided with the test system.

For telephones where the microphone is not fixed relative to the earphone (for example, the candlestick telephone) the test is carried out in free air, in the just-off-hook position and with the earpiece pointed directly at the mouthpiece with a distance of 150 mm between the front planes of each.

Acoustic Shock Test (Acoustical Stimulus)

The acoustic shock test (acoustical stimulus) is designed to check that the sidetone path of the telephone could not cause acoustic shock should the telephone become acoustically unstable. It also checks that the protection against acoustic shock is within the correct part of the telephone circuit.

The test is carried out by applying a sound pressure of +20 dBPa at the mouth reference point over the frequency range 1000 Hz to 4000 Hz at third-octave intervals[3]; applying 25 Ω or 1 MΩ in place of the 600 Ω resistor in Fig. 1 and measuring the sound pressure in the artificial ear. This test is performed at 0·0 km only by using a wideband measuring instrument. The sound pressure is measured wideband because at the levels involved the sound in the artificial ear will have a large harmonic content, thus making the fundamental level much lower than the overall level.

Constant-Current Feed Tests

For this series of tests the circuit configuration shown in Fig. 2 is adopted. A series of currents was chosen to align with those of the British Standard, and the telephone instrument is tested at each of these currents. Some telephones may not be able to draw all the currents without damage, so an overriding limit is set, by the system, equal to that current which would be drawn by the telephone from a 50 V battery in series with a 400 Ω resistor.

Telephones which contain carbon microphones are conditioned prior to the commencement of measurements with the current at which the measurement is to be carried out flowing.

Sending Clipping Test

The sending level at which the telephone under test starts to clip is important since it will determine whether sufficient line signal can be generated by that particular telephone. The fact that third-harmonic distortion increases rapidly with the onset of clipping is used to determine whether or not the telephone is capable of generating the line levels required. The limits are defined as follows:

With the telephone under test connected in the circuit shown in Fig. 2, a frequency response analyser is connected across terminals A and B. The feed current is set to 25 mA and a pure tone of 1000 Hz is applied to the artificial mouth so that the free-field sound pressure at the mouth reference point would be −15 dBPa. The peak-to-peak voltage at this fundamental frequency is measured and the sound pressure (voice drive voltage) increased until either the sound pressure reaches +12 dBPa or the peak-to-peak voltage at terminals A and B is 3·5 V. The third-harmonic distortion is then measured.

The signal sent to line is regarded as not clipping if the third-harmonic distortion is less than 10%.

Receiving Clipping Test

It is also important that, for all reasonable line voltages, the telephone does not clip the signal in the receiving direction. The same criterion is used as for the sending test above (that is, the third-harmonic distortion must not exceed 10%).

The test is carried out under the same circuit arrangement as that for the sending clipping tests, but with the frequency response analyser connected to the output from the artificial ear and the oscillator connected in series with the 600 Ω resistor.

The oscillator voltage is set to a frequency of 1000 Hz and the voltage (EMF source) is increased until either the EMF is +5 dBV or the sound pressure in the artificial ear is +10 dBPa, whichever represents the lower sound pressure in the artificial ear. The third-harmonic distortion is then measured.

Noise Test

In the noise test, 2 noise assessments are made:

(*a*) the noise signal sent to line by the telephone under specific current feeding conditions, and

(*b*) the noise generated within the telephone that could be heard by the user (that is, present in the artificial ear), again under specific conditions of current feeding and termination.

With the telephone connected in the circuit (Fig. 2), the psophometrically-weighted noise level (assessment (*a*) above) is measured, at terminals A and B by averaging over a minimum period of one second.

To measure the noise in the artificial ear (assessment (*b*) above), the measuring instrument is connected to the artificial ear. With the circuit configured as shown in Fig. 2, the psophometrically-weighted noise level in the artificial ear is measured as for assessment (*a*).

The 600 Ω resistor is then replaced with a 600 Ω impedance source, noise generator delivering either −65 dBmp or −62 dBmp (depending upon which noise class was chosen by the telephone supplier) and the noise in the artificial ear is again measured.

The criterion for this test is that the level measured with the noise generator in circuit must be at least 3 dB greater than without it (by using the noise addition rule that 2 equal sources produce a 3 dB rise when added, the telephone is shown to be producing less noise than the noise generator provided that the level in the artificial ear is at least 3 dB larger when the noise source is applied).

If the telephone contains a carbon microphone, the conditioning procedure is adopted, but with a 5 minute undisturbed warm-up period (that is, with the microphone energised) prior to conditioning taking place.

Limits of Signal Sent to Line

Another test which is as important as the sending clipping test described earlier is the test which checks that the telephone will not be capable of sending too great a signal to line.

With the telephone connected as shown in Fig. 2, a 1000 Hz tone at a sound pressure equivalent to +20 dBPa is applied at the mouth reference point.

The output of the telephone is measured by using a wideband high input impedance RMS voltmeter connected across terminals A and B. The criterion in this case being that the output must not be greater than +10 dBV.

Acoustic Shock Test (Receiving)

The acoustic shock test (receiving, or electrical stimulus) is

an assessment of the safety performance of the telephone (that is, if large signals appear at the line terminals, the user must not be subjected to dangerous sound levels in the ear).

The test is carried out at a feeding current of 40 mA in the circuit configuration shown in Fig. 2. The oscillator is connected in series with the 600 Ω resistor and set to deliver an EMF of +24 dBV at third-octave frequencies[3] from 200 Hz to 10 000 Hz.

The sound pressure in the artificial ear is measured by using the wideband RMS voltmeter, since many harmonics will be present. The criterion here is that the sound pressure in the artificial ear must not exceed +24 dBPa, which is equivalent to approximately 118 dB SPL (sound pressure level).

DC Characteristics

To measure the DC characteristics, the telephone is connected into the circuit shown in Fig. 2 and a range of feed currents is applied, in 2 mA steps, from 2 mA to the maximum current (that is, the current equivalent to the 50 V 400 Ω current mentioned earlier). The voltage across the telephone terminals is measured by using a DC voltmeter.

If the telephone has a carbon microphone, it is fed initially with a current of 25 mA, conditioned, and then tested over the current range above.

This test is always performed rapidly so that any change to the telephone characteristics as a result of heating effects or packing of carbon microphones is kept as little as possible.

Impedance Tests

The telephone impedance is measured, by using a frequency response analyser, at various currents in the circuit configuration of Fig. 2, but with the 600 Ω resistor replaced with the network shown in Fig. 3(*a*).

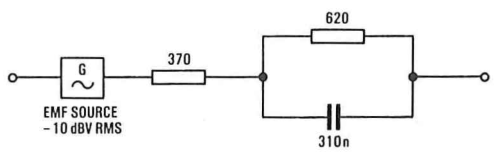
The frequency range used is 200 Hz to 4000 Hz in twelfth-octave steps[3].

Return loss and echo return loss values are calculated for the measured impedance values.

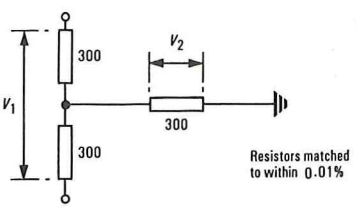
The required telephone characteristics are split into 2 classes:

Class A The return loss relative to the network in Fig. 3(*a*) must not be less than 12 dB and the echo return loss relative to the network over the frequency range 200 Hz to 4000 Hz must not be less than 16 dB.

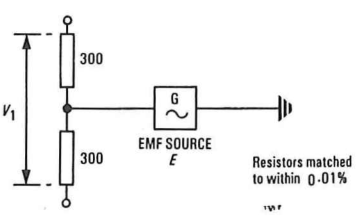
Class B The return loss relative to 600 Ω must not be less than 12 dB and the echo return loss relative to 600 Ω must not be less than 16 dB over the frequency range 300 Hz to 3400 Hz and in the current range 25 mA to 40 mA. For currents over 40 mA, the impedance must lie within the range 140 Ω to 1000 Ω resistive and −350 Ω to +350 Ω reactive.



(*a*) Impedance test network



(*b*) Signal balance about earth network



(*c*) Impedance balance about earth network

FIG. 3—Alternative networks used for specific tests

Signal Balance About Earth Test

The signal balance about earth test applies only to telephones that have an earth connection.

For this test the telephone is connected as shown in Fig. 2, but with the 600 Ω resistor replaced with the network shown in Fig. 3(*b*).

The artificial voice is energised at 1000 Hz so that the sound pressure at the mouth reference point would have been +5 dBPa. Voltages V_1 and V_2 are measured by using a frequency response analyser and the signal balance about earth calculated for each of the various currents from the formula

$$\text{signal balance} = 20 \log_{10} V_1/V_2 \text{ dB}.$$

The criterion being that this balance must not be less than 46 dB.

Impedance Balance About Earth Test

The impedance balance about earth test applies only to telephones that have an earth connection.

The telephone is connected as shown in Fig. 2, but with the 600 Ω resistor replaced with the network shown in Fig. 3(*c*).

For each of the various currents the generator G is set to 1 V RMS for the frequency range 300 Hz to 3400 Hz in third-octave steps[3] and a frequency response analyser used to measure V_1.

The impedance balance about earth is calculated from the formula

$$\text{impedance balance} = 20 \log_{10} E/V_1 \text{ dB}.$$

The criterion in this case is that the impedance balance must not be less than 46 dB.

TELEPHONE TESTING SEQUENCE

There are 2 phases in the testing sequence: calibration and testing.

Calibration

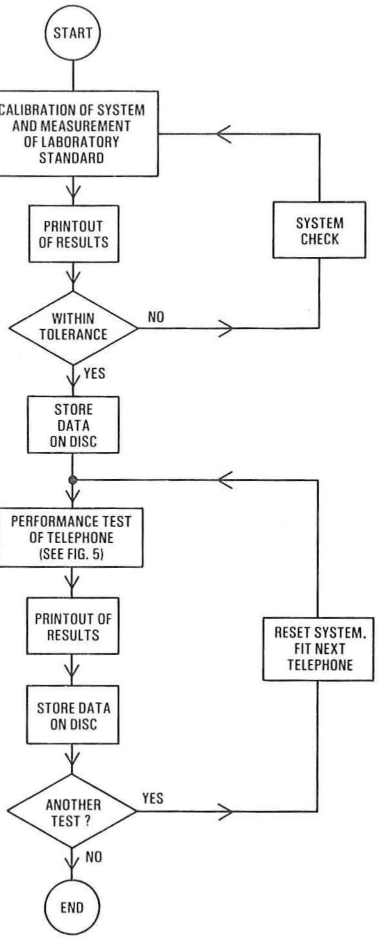
Since the system has been configured by using proprietary testing equipment, such as the frequency response analyser, measuring amplifiers etc., the normal rules for calibration checks on such instruments apply.

Calibration of the complete system is automatically undertaken each time the software is run on the controller (see Fig. 4) and is carried out as follows:

(*a*) The operator is asked to enter the sensitivity (in dBV/Pa) of the microphone to be used for the measurements.

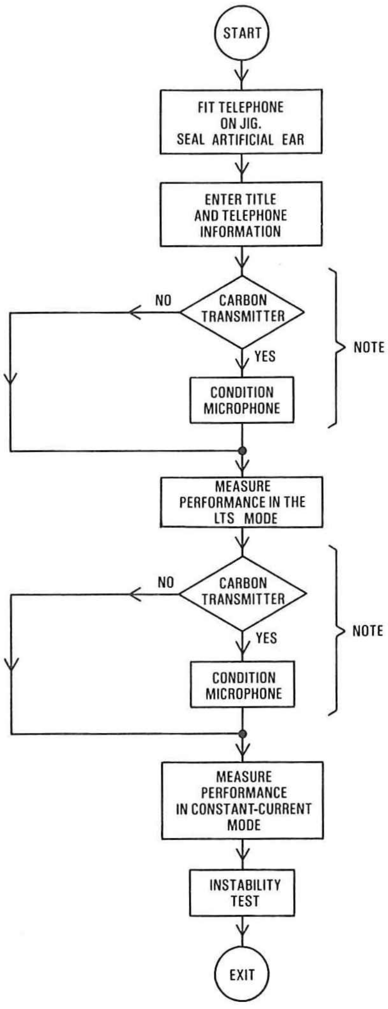
(*b*) A microphone calibrator is then placed on the measuring microphone; the microphone's output is measured by using the frequency response analyser, and the sensitivity is computed. If this computed value is more than 0·1 dB different from the entered value in (*a*), the program stops and the operator is given a warning.

(*c*) The microphone, having been checked, is placed in the reference position in front of the artificial voice (25 mm from the lip-ring and at 90° to the axis, since it is a pressure microphone in a free-field environment) so that a table of voice drive voltages, necessary to achieve the required sound



Note: The laboratory standard may be tested at any time by the operation of one computer key

FIG. 4—Simplified flow chart of system procedure



Note: In practice, the microphone is conditioned at each change of current, and at every change of line length if the transmitter is of the carbon type

FIG. 5—Simplified flow chart of the transmission performance test sequence

pressures at this voice reference point, can be generated.

(*d*) For each of the twelfth-octave frequencies[3], voice drive voltages are generated and iteratively adjusted until the sound pressure, at the reference point, is within 0·1 dB of that required. These voltages are then stored as a reference table for use by the controller, and are filed onto floppy disc for possible later recovery and analysis if required.

(*e*) The program then stops and asks the operator to fit the laboratory standard (a pseudo-telephone supplied with the system) to the LRGP jig and to seal the earpiece to the artificial ear.

(*f*) This standard device is then tested to ensure that the amplifiers, artificial lines and feeding bridges etc. are all within specification. Standard devices are not normally used to compare one system with another since it is the repeatability of a particuliar device on the same system which is being checked.

It is also a feature of this form of calibration check that should the approvals authority need a set of standard results both at the beginning and at the end of each day's testing (as authentication of the correctness of the system for that particular series of tests), then these could be made available.

Telephone Testing

After completion of the calibration sequence, the first telephone instrument for approval is tested.

(*a*) The telephone to be tested is placed on the LRGP jig and the transmission performance tests are performed as detailed earlier and depicted in Fig. 5.

(*b*) The results are output in 2 forms:

(*i*) a computer print-out of all the results, and

(*ii*) a graphic representation of loudness ratings, sending and receiving sensitivity, return loss and DC characteristic (see Figs. 6, 7, and 8 for examples).

In the case of all but two of the graphs, the limits (masks) of the British Standard[5] are automatically plotted so that the operator can see-at-a-glance if failure has occurred.

The 2 graphs not plotted with masks are the sending and receiving sensitivity graphs. This is because several responses (for different line lengths) are plotted on the same axis and to draw 4 sets of masks and 4 sets of data on the same axis would be highly confusing.

(*c*) The data is stored on floppy disc for later retrieval and analysis if required and the program resets the hardware ready to accept the next telephone to be tested.

SYSTEM HARDWARE

The system comprises various proprietary IEEE-488 bus controlled test equipment and measuring devices as follows:

(*a*) A dual-channel correlating complex AC voltmeter and analyser (frequency response analyser).

(*b*) A desk-top computer used as both calculator and instrumentation controller.

(*c*) A computer-controlled microphone amplifier and a psophometer.

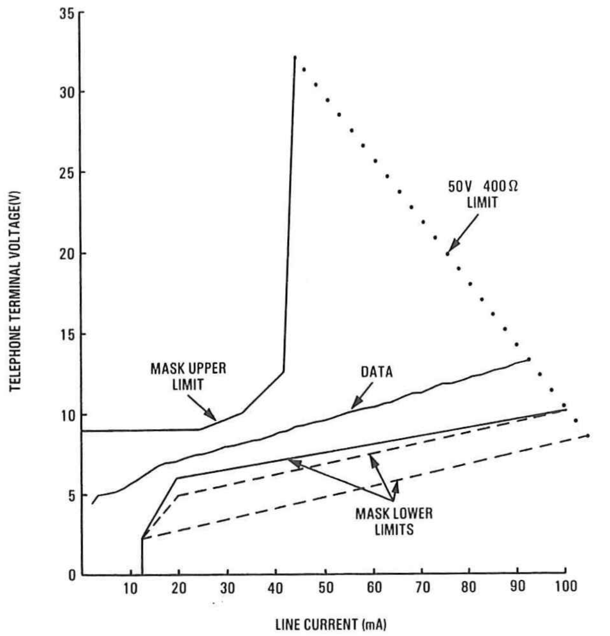


FIG. 6—Example of DC characteristic showing mask and data

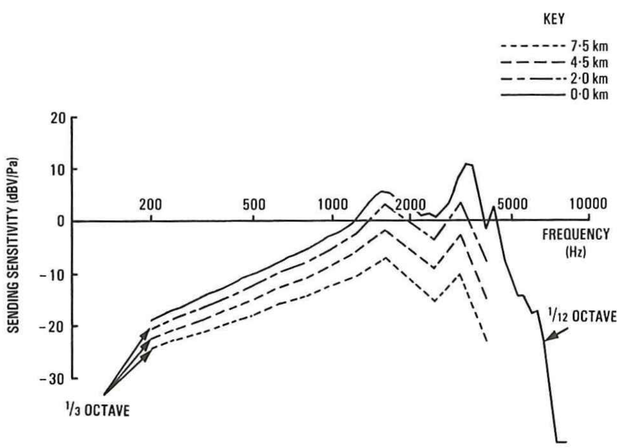


FIG. 7—Example of sensitivity output

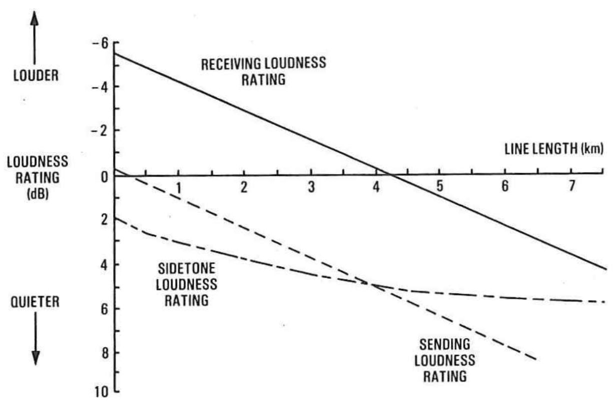


FIG. 8—Example of loudness rating output

(*d*) A computer controlled digital multimeter.
(*e*) Two floppy-disc drive units.
(*f*) A line printer and 4-colour plotter (for data output).
(*g*) A half-inch laboratory-standard measuring microphone, artificial ear, artificial voice and acoustic calibrator.
(*h*) A relay switch matrix.
(*i*) A programmable power supply.

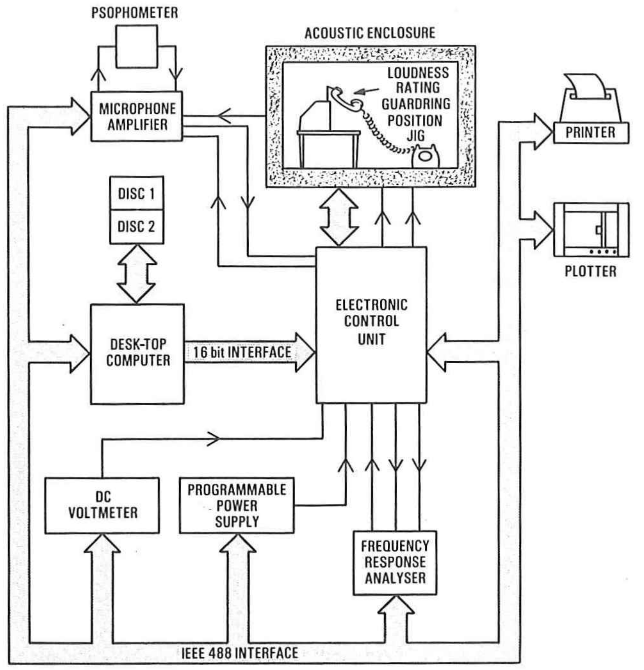


FIG. 9—Block diagram of TIGGER system

This equipment is connected together as in Fig. 9.

In addition to the proprietary measuring equipment, there are 3 main components which have been designed and built by BTRL. These are as follows.

Acoustic Enclosure

The acoustic enclosure is a 1·2 m × 1·2 m × 1·5 m enclosure, built from 18 mm plywood. All surfaces are double layered and the internal edges and joints sealed with mastic to form as near an airtight enclosure as possible. A large door provides access to the interior of the box which is lined (as is the door) with 6-inch-thick acoustic flame-retardant foam. The whole unit is resiliently mounted on a substantial table. This construction method provides the following features which are considered the minimum necessary for telephone measurements of this type:

(*a*) attenuation of about 20 dB of structurally-borne vibration in the frequency range 12 Hz to approximately 1500 Hz,

(*b*) attenuation of externally-generated airborne sound of 28 dB in the 250 Hz octave band to 63 dB in the 4 kHz octave band, and

(*c*) semi-anechoic conditions for the telephone under test, and for the artificial voice.

It is useful to think of the enclosure as a known acoustic termination for the artificial voice associated with the LRGP jig. The most important aspect is that all the systems produced provide the LRGP jig and the telephone under test with the same acoustic environment.

Loudness Rating Guardring Position Jig

The primary function of the LRGP jig (see Fig. 10) is to provide a defined spatial relationship between the artificial ear and the artificial voice. The reference plane of the LRGP jig is that of the artificial ear, just as the reference point of any telephone handset is the earcap since it is this point which decides the position of the mouthpiece in relation to the user's head.

Locating fingers guide the handset into the reference axis and the handset shape determines where the mouthpiece is relative to the artificial voice.

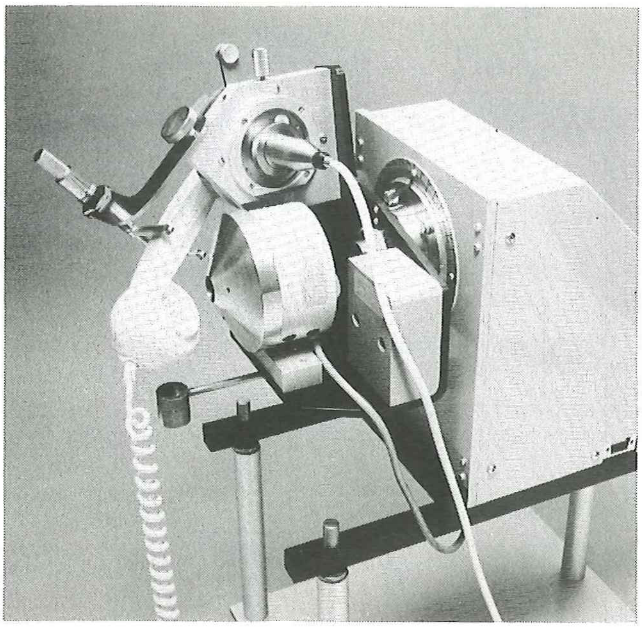


FIG. 10—Loudness rating guarding position (LRGP) jig showing a Handset No. 3 in position.

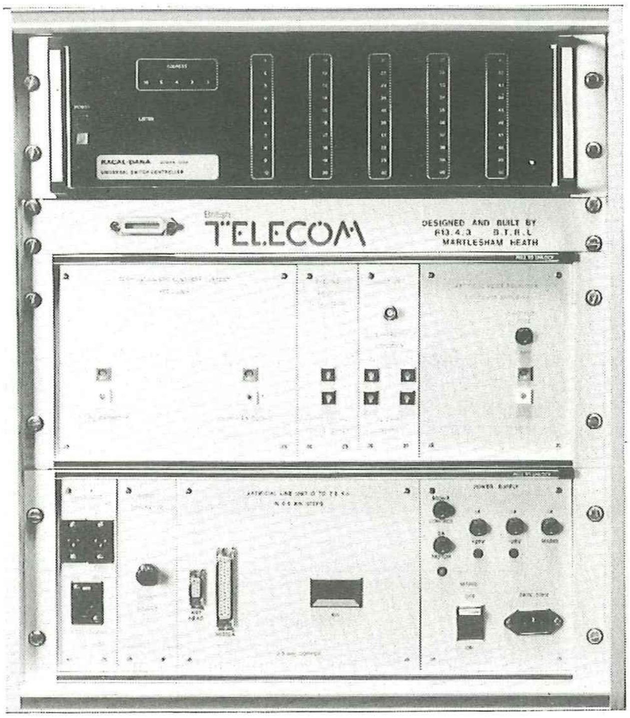


FIG. 11—Front view of the electronic control unit

A secondary function of the LRGP jig is the stepper-motor drive, which provides a closely defined and consistent conditioning cycle for transmitters containing carbon microphones.

A holder is also provided so that the half-inch capacitor pressure microphone can be accurately set to the mouth reference point (25 mm in front of the equivalent lip ring position and at 90° to the voice axis). The microphone in this position is used to iteratively adjust the sound field during the calibration routine.

Electronic Control Unit

The electric control unit (ECU) consists of a 12U high racking system (see Fig. 11) containing the following:

(*a*) an IEEE-488 interface bus-controlled relay switch matrix,
(*b*) termination and constant-current feed module,
(*c*) capacitor feeding bridge (Stone type) module,
(*d*) artificial voice equaliser and power amplifier module,
(*e*) white-noise generator module,
(*f*) artificial line and stepper-motor controller module,
(*g*) power supply module, and
(*h*) two input modules.

Each module has its own specification and function so that changes can be made, and tests of individual modules performed easily, usually by using the same proprietary hardware as is used in the system.

The individual modules are made up as follows:

(*a*) *Termination and Constant-Current Feed Module* This module contains all the terminating networks required for the British Standard[5] and the constant-current feeding bridge (see Fig. 2).

The constant-current feeding bridge contains two 12 H iron-cored inductors and 2 non-polarised 400 μF capacitors. The inductors have been designed to have an inductance of 12 H at 120 mA DC, a self resonance of 6 kHz and a DC resistance of less than 200 Ω.

Because of the constraints imposed by the constant-current power source, the inductors have to be matched to fine limits. A computer program has been written to measure and compare any number of inductors and select suitable pairs.

A 600 Ω to 2 Ω transformer is also included so that a balanced EMF source can be provided from the frequency response analyser oscillator output.

(*b*) *Capacitor Feed Bridge* This is the feeding bridge used to terminate the artificial line (see Fig. 1) forming the local telephone system.

Experiments have shown that the critical component values in this case are the DC resistance of the relay coils. This is adjusted during manufacture so that uniformity between systems and conformity to the standard is maintained.

(*c*) *Artificial Voice Equaliser and Power Amplifier* The equaliser is a 5-stage state-variable system designed by using an iterative computer program operating on data which was an average of 10 Bruel and Kjaer artificial voice transfer functions. Without the further software equalisation, this equaliser/amplifier combination gives a sound field which has a maximum deviation of ± 2 dB from 200 Hz to 10 kHz. The amplifier section is a class AB DC coupled thermally-compensated design capable of providing +24 dBV at 0·1% total harmonic distortion.

(*d*) *Noise Generator* This module supplies white noise from a 600 Ω source at levels that can be varied by a front-panel control. Noise is generated by a reverse-biased zener diode and amplified to a suitable level. To ensure noise stability, the zener diode is mounted in an oven kept at 80°C.

(*e*) *Artificial Line and Motor Control Module* The artificial line is built up from 0·1 km sections of 0·5 mm simulated copper conductor (see Fig. 1). These small sections are connected to form 4 km, 2 km, 1 km, and 0·5 km sections which can be cascaded in a binary sequence to form the line lengths required for the tests. The artificial line is controlled by the 16-bit parallel bus from the computer, not the IEEE-488 bus.

The stepper motor in the LRGP jig (used for carbon-transmitter conditioning) has a proprietary control board built into this module and is controlled by the 16-bit parallel bus. The current feed resistors dissipate some 30 to 40 W and are mounted in a protective cage at the bottom of the racking system.

Access is provided, on the rear of the ECU so that ancillary units for performing other tests can be added as extra modules (for example, for testing loudspeaking telephones, PBXs etc.), if this should be required.

SYSTEM SOFTWARE

The software has been designed to include the following features:

(*a*) Self-naming filing system for the calibration and laboratory standard data based upon the date; for example, 0403C1 would be the calibration data file for the first calibration 4 March and 0403L1 would be the laboratory standard data file. Up to 9 calibrations and 9 laboratory standard files may be created during any one day; the last digit of the file name being incremented each time.

(*b*) An ABORT facility is provided so that the system may be reset to the START-OF-TEST condition at any time and testing recommenced without the need to recalibrate.

(*c*) A check is kept on the peripheral devices as follows:

(i) disc drives are scanned for the presence of discs and if not present or if the disc is full a warning is given and the program halted until the disc is replaced with an initialised disc—no loss of data occurs;

(*ii*) the plotter is scanned for its identifying code and if paper is not present or paper needs to be loaded the operator is warned;

(*iii*) the printer is constantly scanned during printing for the presence of paper and if paper is not present the operator is again warned.

(*d*) The telephone data collected during tests is filed under file names entered by the operator.

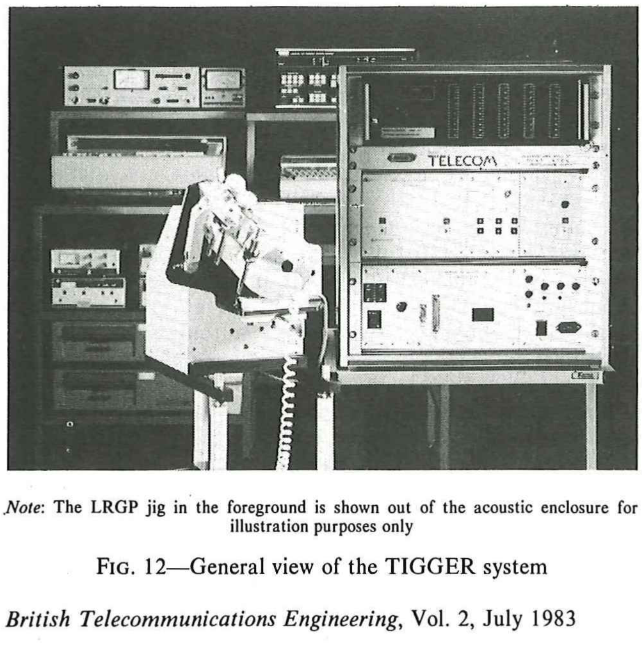
(*e*) Software is provided for data retrieval as part of the package.

(*f*) A system test program has been written and is used to check the complete system (both proprietary and BT produced) as and when required.

(*g*) A suite of programs is also used to check the performance of individual modules either during manufacture or as individual items should the occasion demand it.

CONCLUSIONS

BT and the British Standards Institution's test laboratory have been using this system (see Fig. 12) to assess the performance of telephones for over 12 months and have experienced no major difficulties. These test houses have, as yet, been carrying out only a limited series of tests, but it is hoped to update these as soon as the full approvals standard is available.



Note: The LRGP jig in the foreground is shown out of the acoustic enclosure for illustration purposes only

FIG. 12—General view of the TIGGER system

One system with amended software, is in use by a manufacturer as a quality assurance system.

At least 6 more systems have now been ordered with the possibility of other orders to follow.

With very few module changes and modified software the system is easily adaptable to test to many objective telephone transmission performance testing requirements.

ACKNOWLEDGEMENTS

Acknowledgement is made to E. G. T. Johnson, BTRL, for his assistance in the production of this article.

References

[1] CROWE. J. M. British Standard For Simple Extension Telephones: Transmission Aspects. *Br. Telecommun. Eng.*, July 1983, **2**, p. 64.

[2] CCITT Recommendation P76 Determination of Loudness Ratings, Fundamental Principles. Yellow Book, **5**, 1981.

[3] International Standards Organisation ISO 266: 1975 Acoustics—Preferred frequencies for measurements.

[4] CCITT Recommendation P64 Determination of sensitivity/ frequency characteristics of local telephone systems to permit calculation of their loudness ratings. Yellow Book, **5**, 1981.

[5] British Standards Institution BS 6317: 1982 Specification for simple extension telephones for connection to the British Telecommunications public switched telephone network.

APPENDIX 1
CONDITIONING OF CARBON MICROPHONES

In order to obtain repeatable test results from instruments fitted with carbon microphones, it is necessary to stop the carbon granules in the microphone from packing in the granule chamber of the microphone. (This can cause loss, or variation in, sensitivity; excess noise etc.)

One way of preventing packing is to shake-up the microphone in a known manner, and for these tests the following procedure was chosen.

Handset-Type Telephones

For telephones where the microphone is fixed relative to the earpiece (that is, handset telephones):

(*a*) the handset is placed in the LRGP jig[2],

(*b*) the feed current is switched on,

(*c*) after 5 s, unless otherwise stated, the microphone is conditioned by moving the complete handset:

(*i*) clockwise at full speed through 10° to bring the ear reference plane vertical,

(*ii*) clockwise at full speed through a further 168°,

(*iii*) clockwise at slow speed through a further 12° (so that the handset can be brought to rest without sudden jolts which may repack the granule bed),

(*iv*) stop for 300 ms,

(*v*) anti-clockwise at full speed through 168°,

(*vi*) anti-clockwise at slow speed through a further 12°,

(*vii*) stop for 300 ms,

(*viii*) repeat steps (*ii*) to (*vii*) inclusive,

(*ix*) repeat steps (*ii*) to (*vi*) inclusive, and

(*x*) anti-clockwise at slow speed through 10° to bring the handset back to the starting position.

The axis of rotation passes through the centre of the lip-ring and is perpendicular to the plane of the lip-ring.

Non-Handset-Type Telephones

For telephones where the microphone is not fixed relative to the earpiece the following procedure is adopted:

(*a*) the feed current is turned on,

(*b*) five seconds after the current is turned on a pure tone signal with a sound pressure of +5 dBPa (at the mouth reference point) is applied to the artificial mouth at a frequency of 200 Hz,

(*c*) the frequency of this signal is increased over a time interval of some 8 s to a maximum of 8000 Hz in third-octave intervals[3] while a sound pressure of +5 dBPa is maintained at the mouth reference point.

The Use of Gate Arrays in Telecommunications

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UDC 621.38.049.776: 621.39: 681.3

This article briefly describes a few examples of the use of gate arrays designed at British Telecom Research Laboratories before proceeding to discuss the present and possible future trends, particularly in the field of computer automation, that undoubtedly hold the key to the continuing growth in the use of gate arrays. This article is based on a paper[1] *presented at the Institution of Electrical Engineers (IEE) Communications '82 Conference, Birmingham, and is reproduced with the permission of the IEE.*

INTRODUCTION

British Telecom's (BT's) modernisation programme involves an increasing proportion of electronic equipment that is dependent on semiconductor components. The costs of floor space, power supplies, cooling equipment and reliability considerations dictate that large-scale integrated (LSI) components will be used for larger proportions of the electronic functions. However, a significant requirement has been identified in between the extremes of standard parts and large-volume hand-crafted custom-designed LSI parts; this is for medium-volume LSI parts, where the volume is such that the amortised development cost may be more significant than the unit production cost. It is into this market that the gate array has been successfully introduced, and has brought shortened development times (and hence lower costs) for custom-designed LSI circuits.

However, engineers quickly became aware that the short development times of gate arrays led to other benefits such as rapid modification or the reworking of development circuits, and the earlier introduction of new equipment that may often be more important than the final unit cost. The regular, defined structure and tested characteristics of gate arrays lend themselves particularly to computer automation, which has led to further shortening of timescales and the ability to tackle larger gate arrays.

Thus, in both BT and the electronics industry in general, these factors have led to explosive growth in the use of gate arrays over the past few years, pioneered mainly by the computer industry and now being followed rapidly by the telecommunications industry.

APPLICATIONS

Gate arrays designed by British Telecom Research Laboratories (BTRL) have been used in a wide variety of applications, ranging from terminal equipment, through transmission systems and private automatic branch exchanges (PABXs), to System X main exchanges. Early uses of gate arrays, when only small arrays (< 500 gates) were available, are well illustrated by the 4 gate-array circuits designed by BTRL and used in the Monarch PABX [2]. Two of the circuits (one or other provided on a one-per-line basis) perform interface functions on the signalling data. In telecommunications, where interfaces between different speeds and protocols are often needed, interfacing was one of the commonest early uses of gate arrays, replacing several medium-scale integrated (MSI) and small-scale integrated (SSI) components. The third gate array is also an interface circuit, this time between several incompatible standard LSI components in the operator's console [3]. The fourth circuit provides a somewhat different function, in that it monitors the microprocessor controlling the PABX and, if correct signals are not received, gradually rolls-back the system in stages until either correct operation is restored or the PABX has to be closed down [4].

Many other gate-array circuits have been designed in BTRL for a variety of applications, but a noticeable trend has been the increasing size of the circuits required. For instance, whereas the first circuits for Monarch mentioned earlier were accommodated on a 340-gate array, the latest circuit designed on a Ferranti array by BTRL for System X required a 2000-gate array (see Fig. 1). In addition, rather than being merely a collection of random logic — often described as *logic glue* — each circuit has become a more distinct functional entity; an example is a recently designed circuit on a 1440-gate ISOCMOS array, which replaces 2 full printed-wiring boards (PWBs) forming the entire logic of a portable tester (see Fig. 2).

TECHNOLOGY

In the UK, Ferranti, with their bipolar collector diffused isolation (CDI) arrays, pioneered the commercial use of gate arrays and for many years this was by far the most widely used technology. However, over the past few years virtually all current technologies have been used, with varying degrees of success, for gate-array manufacture, and each supplier extols the virtues of his own particular array. As a purchaser of telecommunications equipment, BT looks for certain features in an array, such as low cost, high reliability, low power dissipation, and multiple sources of supply (including at least one local source). Although transmission speeds are increasing, much of the current telecommunications equipment operates at relatively low (< 10 Mbit/s) speeds. If this is combined with the need for low power dissipation, especially for line-powered equipment, modern complementary metal-oxide semiconductor (CMOS) technologies with their automatic powerdown capabilities seem to provide the best technology for most telecommunications applications.

Emitter-coupled logic (ECL) gate arrays, which are widely used in the computer industry, will continue to be the only solution for very high-speed applications, despite their very high power dissipation and thus their limited complexity. For the intermediate range of frequencies (for example, tens of Mbit/s), a wide range of possible technologies is available, but it seems likely that mainstream or

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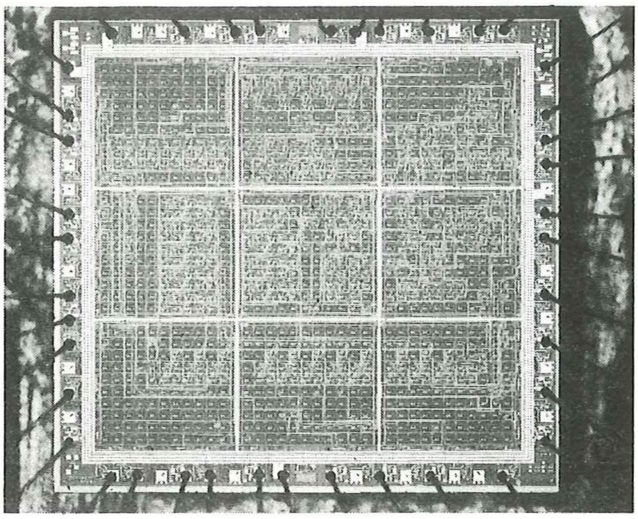
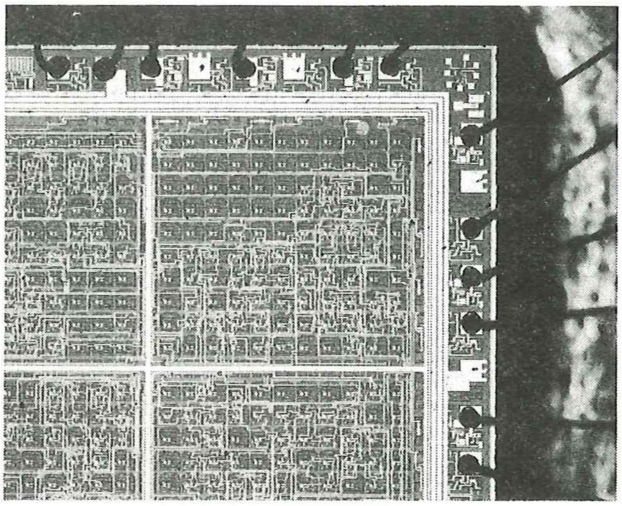


(*a*) Complete IC



(*b*) Enlarged view of IC shown above

FIG. 1—A 2000-gate Ferranti CDI gate array designed in BTRL for System X

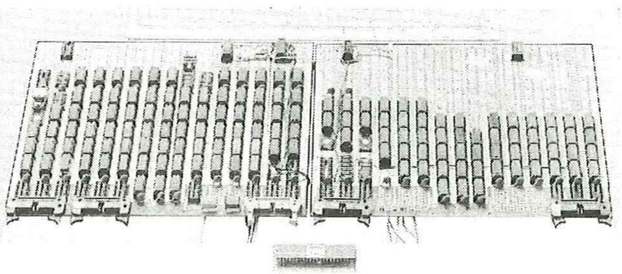


FIG. 2—A 1440-gate Micro Circuit Engineering CMOS gate array designed in BTRL, and the 2 PWBs it replaces

well established technologies such as CDI or the advanced Schottky transistor-transistor logic (TTL) processes will capture this market, though the individual choice will probably be more dependent on the computer aids available.

In the same way that very-large-scale integration (VLSI) custom-designed microchips follow the advances in technology pioneered for memory devices, so gate arrays use the technology when it is proven on custom designs. However, the intervals between implementation as a custom microchip and use for a gate array are shortening, and the increasing demand for ever larger gate arrays is forcing the gate-array manufacturers to more advanced technologies. Already 8000-gate arrays are on the market and several manufacturers are developing larger arrays. To keep chip sizes down to economic proportions, 3 μm or even 2 μm feature sizes are being used in the large CMOS arrays. The use of 2 layers of interconnect metal has been standard for some years for ECL and some TTL arrays, and most manufacturers now agree that, on the larger CMOS arrays, 2 interconnect layers are essential to give adequate interconnectivity and reasonable chip size. A portion of a recently-designed 2-layer metal ISOCMOS circuit is shown in Fig. 3. IBM use 3 layers of metal on its bipolar arrays[5], and have recently shown that considerable density improvements can be achieved by using 4 layers[6].

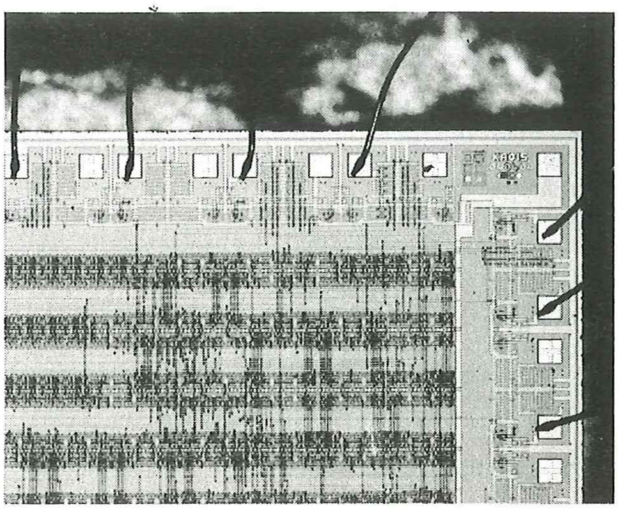


FIG. 3—Part of a Plessey 2-level metal CMOS gate array designed in BTRL for use in an ISDN transmission interface unit

A final essential point on technology is the close interaction needed between the design of the uncommitted array and computer automation. Automation of an array originally designed for manual layout is most unlikely to lead to an economic product. For effective use of computer aids it is vital that an array should be designed from the start with automation as a prime goal.

COMPUTER AUTOMATION

The regular well-characterised structure of gate arrays lends itself to computer automation, and it is clear that, as arrays get larger and circuits more complex, automation is essential to keep down timescales and costs.

Two approaches are possible: either general-purpose programs are used for a range of applications (possibly including board design and hand-crafted circuits), or a special-purpose software suite is written for one class of arrays. The choice between these approaches will depend on the particular circumstances, but there is clearly a trade-off in software development, flexibility and program run times. Whichever approach is taken, it is essential that the design, layout etc. start from a single database of the circuit description. From this single point, the 3 main activities can commence.

Logic Design

Most modern gate-array systems use libraries of pre-characterised and routed logic functions, so that the designer need not consider transistor interconnections, only functional connections. This leads to the need for only a simplified logic simulator with timing information characterised and pre-defined under worst-case conditions. The interconnect loading on each logic function will not be known until after layout, hence, the initial simulation will probably include nominal loading, and a means must be available of extracting real loading and using it in the simulator.

In general, simulators are a fairly well established area and most gate-array suppliers use, or have available for use, a logic simulator which, though rarely ideal, normally provides an adequate design tool.

Test-Program Generation

Although the problems of testing have always been acknowledged, in most cases test-program generation (TPG) has remained a relatively neglected area. However, it is now being realised that TPG can take more time than design and layout together if suitable steps are not taken early in the design phase. It is essential that TPG is considered and, if possible, completed before layout is started. For random unstructured logic circuits, automatic TPG is unlikely to be very efficient, and it rarely picks up the few remaining faults on a circuit. For this type of circuit, BT uses a testability analysis program[7] during circuit design to highlight testability problems and to suggest possible solutions. Manual TPG is then employed and the test program verified and improved by using a fault-simulation program until 100% single stuck-at-fault coverage is achieved.

For larger and more complex circuits, more formalised procedures must be introduced; for example, self-testing on the chip[8], or scan-path design techniques[9]. These, or similar techniques, are necessary to ensure that, in conjunction with computer aids, TPG times are kept to manageable proportions while fault coverage is still achieved.

Layout

Automated layout has always been a prime goal for gate-array manufacturers; in particular, with bipolar arrays, where 2 or 3 levels of metal have been available, some impressive results have been achieved[5]. However, more than in any other phase of chip procurement, the success of automatic layout depends critically on the design of the uncommitted silicon chip. Attempts to automate the layout of gate arrays intended for manual design have largely been unsuccessful and, if larger gate arrays are to be used and automatically laid out, it is essential that the uncommitted chip must be carefully designed with this in mind.

However, a layout-to-logic checking program would be a more useful design aid for smaller arrays designed for manual layout than an aid that attempts to automate a layout. Such a program is a relatively straightforward item in view of the pre-defined positions of all the transistors. As technology improves and silicon area can be traded for design time, the move towards automated layout will increase. Although automated layout is not quite as efficient on silicon area as manual layout, it will give a much faster design time, and thereby further enhance the economic advantages of gate arrays.

THE UK 5000 PROJECT

One example of a project aimed at fulfilling the requirements for advanced gate-array products is the UK 5000 project[10]. This project, set up after discussions chaired by the Department of Industry, involves 7 UK organisations (BT, Ministry of Defence (MoD), Science and Engineering Research Council (SERC), International Computers Ltd. (ICL), General Electric Company plc (GEC), Standard Telephones and Cables plc (STC), and Telephone Manufacturing Company Ltd. (TMC)) collaborating to produce an integrated system of computer-aided design (CAD) and silicon design.

The project team has chosen to write a suite of software dedicated to gate-array automation (rather than use general-purpose software) and to design an uncommitted silicon chip specifically for the project. The aim is to automate totally the logic design, test-program generation and circuit layout from a simple description of the logic circuit. The 5000 usable gate CMOS array, with 2 levels of metal interconnect, will be one of a family of similar arrays and will be designed so that the silicon wafers are multi-sourceable.

Because the work is being split between a large number of participants, it has been necessary to adopt very high standards of documentation and transportability of software to ensure that the program suite will run on all the participants design computers. Too often, CAD programs are dedicated to one machine, but it is anticipated that the mode of working in the UK 5000 will lead to indirect benefits of ease of maintenance and upgrading because of the enforced modular and transportable nature of the software.

CONCLUSION

Gate arrays have grown rapidly over the past few years in size, in the complexity of their circuits and in their areas of application. It is the author's view that this growth will continue and that gate arrays will be used in an increasing number of applications. It is expected that 2 or 3 μm CMOS arrays will fulfil a large proportion of telecommunications needs over the next few years. CDI, advanced Schottky TTL and, for the highest speeds, ECL arrays, are expected to meet the remaining requirements. Because of the reduced development times and costs, and the higher probability of first-time working, it is expected that manufacturers offering full computer automation of their large arrays ($>$ 1000 gates) will capture the market from those still relying on manual techniques.

ACKNOWLEDGEMENTS

Acknowledgement is made to the Director of Research, British Telecom for permission to publish this paper.

References

[1] GRIERSON, J.R. The Growing Use of Gate Arrays in Telecommunications. IEE Conference Publication No. 209 [Communications 82], 1982, pp. 58–60.

[2] POTTER, A.R. Monarch 120—A New Digital PABX. *Post Off. Electr. Eng. J.*, Apr. 1980, **73**, p.14.

[3] WILLETT, G. The Operator's Console for the Monarch 120 PABX. *ibid.*, Oct. 1980, **73**, p.138.

[4] WATERS, R.E. Monarch 120—Maintenance Facilities. *ibid.*, July 1981, **74**, p.99.

[5] IBM. The System 370 Processor Chip: A Triumph For Automated Design. *Electronics*, 1980, **53**(22), pp.139–147.

[6] BRENNER, S., *et al.* A 10 000 Gate Bipolar VLSI Masterslice Utilizing Four Levels of Metal. Proc. 1983 Internat. Solid State Circuits Conf., New York, USA, 1983.

[7] BENNETTS, R.G., *et al.* CAMELOT, a Computer Aided MEasure for LOgic Testability. IEEE Internat. Conf. on Circuits and Computers, New York, USA, 1980.

[8] KONNERMANN, B., *et al.* Built-In-Logic Block Observation Techniques. IEEE Test Conf., Cherry Hill, New Jersey, USA, 1979.

[9] EICHELBERGER, E.B., and WILLIAMS, T.W. A Logic Design Structure for LSI Testability. *J. of Design Automation and Fault Tolerant Computing*, 1978, **2**, pp.165–178.

[10] GRIERSON, J.R., *et al.* The UK 5000—Successful Collaborative Development of an Integrated Design System for a 5000 gate CMOS Array with Built-in Test. Proc. 1983 IEEE Design Automation Conf., Miami, USA, 1983.

The Impact of the Invention of Polyethylene on World Telecommunications

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UDC 621.39:678.742.2:608.1

1983 is the golden jubilee of the invention of polyethylene (PE) by Imperial Chemical Industries in 1933. One of the industries on which this invention has had a major impact is telecommunications. As one of the only two countries in 1946 that possessed PE manufacturing facilities (the other was the USA), the UK and British Telecom have played major roles in the development of the uses of PE in telecommunications. This article describes in historical sequence the barriers to the acceptance of PE in telecommunications practice, the way these barriers were overcome, and the financial and operational benefits that have accrued. This article is based on a paper presented at a Plastics and Rubber Institute Conference held on 8–10 June 1983 to celebrate the 50th anniversary of this invention.

INTRODUCTION

Polyethylene (PE) now virtually monopolises 3 areas of telecommunications transmission practice. These are: the dielectric insulation (solid or partly air spaced) of land and submarine coaxial cables; wire insulation for external local distribution and local trunk cables; and sheathing of all types of external cable. These eventual uses were all foreseen at the very first meeting between the Imperial Chemical Industries (ICI) and the British Post Office, now British Telecom (BT), in 1937. What was probably not foreseen was the enormous development effort by all concerned that would be needed to establish PE in its present dominant position.

HISTORY

The invention of PE in 1933 at ICI has been fully described by Gibson[1]. In August 1937, ICI invited Messrs. Radley and Richards of the BT Research Department to Winnington, Cheshire, to discuss possible applications of PE in telecommunications. A summary of this meeting is given in Appendix 1.

By 1939, BT was sufficiently impressed with the potential of the new material to order a PE-insulated North Sea telephone cable[2]. A BT Research Report of October 1939 reiterated doubts, in terms of its suitability for cable sheathing, about the low elongation-to-break performance of two grades of PE with molecular weights of 9000–12 000 and 15 000–20 000. Also recorded was that some extrusions of 0·625 inch (15·8 mm) diameter on 0·25 inch (6·3 mm) conductor had shown a tendency to crack on storage. This was attributed to a combination of the sharp melting point of low molecular weight PE and faulty extrusion conditions. The manufacturers proposed the addition of polyisobutylene as an extrusion aid[3,4].

With the outbreak of war, civil development of all uses of PE virtually ceased as all available production was diverted to military use in radar applications. By the end of the war, production in the UK was about 2500 t per year.

In the USA, the commissioning of large PE production plants by Union Carbide (UC) and Dupont not only provided all the radar-grade material needed, but also a surplus available for other cable uses. Among these were the US Army Signal Corps' assault wire and the Navy's advanced-base underground telephone wire. In view of these developments, it is hardly surprising that the cessation of hostilities in 1945 found the USA better placed to develop the civil uses of PE in telecommunications than any other country.

Improvements in the physical and mechanical properties of low-density polyethylene (LDPE) between 1937 and 1945 had removed most of the early fears about its toughness as a wire covering and/or sheath; the way was thus clear for its rapid exploitation. As a cable sheath, however, the then unsolved problem of the undesirably-high water-vapour permeation rate (WVPR) placed restrictions on the areas of use of plain-PE sheaths.

A point that needs to be appreciated is that every Telecommunications Administration faces a unique set of problems and constraints in providing its country with a cheap and effective system. Countries differ in their geography, topography, distribution of customers between towns and rural areas, local environments, competing materials price structure, and the existing historical telecommunications practices. The new has to be compatible with the old. For these reasons developments accepted with alacrity in one country may be of little interest to another country.

CABLES FOR LOCAL EXCHANGE CONNECTIONS

Wire Insulation—Unpressurised Cables

The pre-war standard wire insulation for local cables was either helically lapped paper or formed paper (pulp), the latter used only in countries with a large internal demand; for example, the USA. In the early post-war years, PE-insulated wire was not price-competitive with paper/pulp on a 1:1 basis. PE-insulated and sheathed cable was, therefore, developed initially for those areas of the network that showed a high fault rate with the traditional paper/lead cables. These areas were the fringes of urban districts where the network forks into a multiplicity of small-diameter cables, and rural areas with long runs of aerial or direct-bury cable. It was argued at the time that the all-plastic cable would be immune to the frequent circuit failures induced in paper cables by small amounts of incoming water from corroded or cracked sheaths.

One of the first production cables of this philosophy was a robust single-pair PE-insulated and sheathed cable developed by BT in 1948 to overcome a shortage of the light poles used for rural distribution. It could be mole-ploughed into fields and road verges and was particularly suited to providing service to farms[5]. The success of this cable led to a

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steady expansion of the use of small all-PE cables until, by 1960, all cable sizes under 200 pairs were of this type.

In the USA, PE was even less competitive with pulp insulation than in the UK and extensive deployment of plastic-insulated cables (PIC) did not occur until 1955. The Bell *ready access* system needed an aerial cable that was viable at ambient humidities and the overall economics of the system permitted the use of PE insulation[6]. Aerial cables were provided with an ALPETH sheath (described later in this article). The success of this PIC cable led to its further use as buried cable using a more sophisticated design of sheath.

These cables were regarded initially as very successful, and wherever they were installed fault rates decreased by around 70%. It was only with the passage of time that doubts about the basic philosophy emerged. For example, when water enters a paper cable, loss of circuits occurs immediately, but the swelling of the paper/pulp limits the spread of water into the cable. Remedial action is, therefore, usually prompt and effective. When water enters an air-filled all-plastic cable, there may be no initial adverse effects at all. The spread of water into the cable proceeds unchecked and as the cable slowly fills with water, creeping degradation of the transmission characteristics occurs. Eventually, a pinhole in a wire insulation is short-circuited to earth or to another pinhole causing a faulty circuit and rapid wire cut-off by electrolysis. This wire cut-off may occur hundreds of metres from the point where water is entering the cable. Fault finding is thus difficult and, by the time remedial action becomes imperative, the cable length may be damaged beyond repair.

The initial response by all Administrations was to address the wrong problem. Efforts were made to improve the quality of wire insulation by detecting and repairing pinholes, joint closure procedures were tightened, and the use of water detectors was considered. In hindsight, all this was just galloping into a blind alley—there was no way in which an economical and satisfactory land cable could be made by attempting to give submarine cable integrity to each pair of insulated wires.

The first halting efforts to address the right problem (that is, how to prevent water contacting the cable core) was made by BT in 1962. This was a scheme to insert sticky-putty water-blocks every 20 yards (18 m) along the core. The philosophy was that by restricting water entry from a fault to 18 m of cable, the overall cable transmission would be little affected, and the statistical probability of the water contacting a pinhole reduced. The idea was not entirely successful. The blocks were difficult to insert at the manufacturing stage, the materials that worked best as water blocks were unpleasant to handle, and cables sometimes resembled a boa constrictor unsuccessfully attempting to digest a series of large mice.

The conceptual jump that fully resolved the problem was made by G. A. Dodd of British Insulated Callender's Cables Ltd. (BICC) in 1963[7]. This was to replace the entire air-space of the cable core by a soft inert water-repellent filling, thus leaving nowhere for the water to go. However, this innovation, which was immediately accepted as providing a sound theoretical base for unpressurised cable design, raised a further problem. One factor affecting the transmission performance of a twisted pair is the interwire capacitance. This is controlled largely by the interwire distance (controlled by the thickness of the insulation) and the weighted mean of the permittivity of the surrounding medium. In the older design cables, this permittivity is intermediate between that of the insulation and the air surround. Replacing the air by a material of a higher permittivity increases the mean permittivity and thus the interwire capacitance.

There are 2 ways in which the interwire capacitance in filled cables can be restored to its original value. The first is to leave the insulation thickness and overall cable diameter unchanged and inject gas into the insulation; that is, use cellular insulation. The second is to keep the materials unchanged, but to increase the radial thickness of the wire insulation and thus increase the interwire separation. Both methods have their advantages and disadvantages as indicated in Table 1.

In Japan, where the local environment favours aerial cable for local distribution, modified polybutene is used as the filler and solid LDPE is used as insulant in the relatively small amount of filled cable that is manufactured.

Since its inception in 1963, filled cable has been adopted worldwide as the standard for local unpressurised cable, with a further welcome decrease in the incidence of cable faults (see Fig. 1). Currently, a number of different realisations of the filled cable are in production; these are described in Table 2.

Wire Insulation—Main Local Cables (Pressurised)

Main local cables are those that carry relatively large numbers of local circuits from the exchange to the cabinets, where the change to filled cable occurs. They can be as large as 75mm in diameter and carry up to 4800 circuits. Because of their relatively small numbers and (postwar) protection by gas pressurisation systems, the fault rate was much lower than the unpressurised parts of the local network. The technical advantages of replacing paper/pulp by PE were expected to be marginal and the replacement was simply a question of economics.

TABLE 1
Comparison of Methods of Maintaining Interwire Capacitance

Method	Advantages	Disadvantages	Favoured by
Use of cellular insulation	Maximum economy of materials Unchanged dimensions of insulated wire diameter and cable diameter	Less robust wire covering if PE used Initial doubts about long-term integrity of the filler/cellular insulation combination Change of technology to cellular extrusion	BT
Increased thickness of insulation	Retains robustness of wire covering Less initial doubt about the stability of the solid insulation/filler combination	Increased quantity of material needed for insulation and sheath Diameters of insulated wire and sheath increased	Bell System

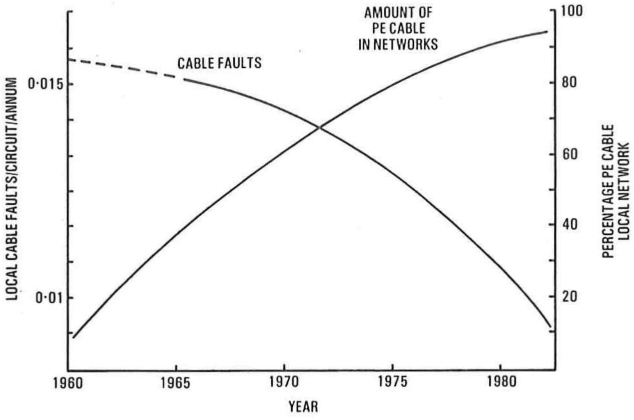


FIG. 1—Percentage of PE-sheathed cable in the local network, and incidence of cable faults

TABLE 2
Variations on Local Unpressurised Filled Cable

User	Insulation Type	Filling Compound
BT	MDPE cellular	Petroleum jelly
Bell System	HDPE solid	Flexgel (gelled oil)
Japan	LDPE solid	Modified polybutene

LDPE: low-density polyethylene
MDPE: medium-density polyethylene
HDPE: high-density polyethylene

It was thus not until the mid-1970s that the maturing technology of cellular extrusion allowed the replacement of lapped-paper insulation on BT cables with thin-wall cellular medium-density polyethylene (MDPE), at a modest saving in costs.

In the USA, with its massive installations for producing pulp-insulated wire at very-low costs, the economic turning point has yet to be reached. A description of the BT main local cables using cellular insulation is given at Appendix 2.

In Japan, congested city centres biased development towards cable structures that were highly economical of expensive duct space. The result was a fine-conductor (0·32 mm copper) quad-design cable insulated with cellular high-density polyethylene (HDPE) produced by a novel solvent coating process developed originally by Rokunohe of Nippon T T[8]. Use of this cable was scheduled at the equivalent of approximately 1600 km of 3600-pair cable by 1968[9].

Sheaths for Local Distribution Cables with PE Insulation

On cables with wire insulation insensitive to water vapour, the function of the sheath is merely to provide a robust mechanical envelope that protects the cable core during transportation, installation and normal in-service hazards. Until 1947, the traditional sheath had always been hot-pressed lead or lead alloy.

In the UK between 1947 and 1950, the cost of a PE sheath was little different to that of lead, and the choice of PE for the first generation of PE-insulated cables was dictated by a number of subsidiary factors: small-diameter lead cables had a poor history of failure by fatigue-cracking and corrosion; there were doubts about the wisdom of extruding a lead sheath on to a thermoplastic-insulated core; the reduced weight of PE-sheathed cable reduced transport costs, and the lower coefficient of friction together with its reduced weight enabled longer lengths of cable to be drawn into ducts.

After 1950, with the steady fall in the price of PE relative to lead, the advantages in the use of PE steadily increased until its position as the preferred choice was unassailable[6].

Only one cloud cast its shadow over the increasing use of PE for cable-sheath applications—the discovery that PE showed environmental stress cracking (ESC) in the presence of a wide range of potential contaminants such as polar solvents, surface-active materials and silicones[10,11]. This was totally unexpected and for many years after the initial discovery, no fully satisfactory theoretical explanation was available to guide work on solving the problem. In 1951, however, the development by Bell Laboratories of a quick and effective test for evaluating the stress-crack resistance (ESCR) of PE materials[12] enabled much work by PE producers and users to overcome the problem at the technical level. That test is now standardised as ASTM† 1963. The move to materials with improved ESCR has, in general, been in the direction of lower melt indices; narrow, rather than wide, molecular weight spreads; copolymers containing small amounts (for example) of vinyl acetate; and improved processing characteristics. The ESCR of currently available sheathing grades of PE is fully adequate for all present needs. (See Fig. 2.)

The total number of PE sheaths that failed compared with the incidence of, for example, fatigue and corrosion failures on lead sheaths was minimal. The improvements in properties of PE sheathing grades from 1950 to 1980, are shown at Appendix 3.

In the UK, the sheaths of PE-insulated cables were plain extrusions. In the USA, where lightning protection was regarded as essential, the ALPETH sheath was used on aerial cables, but without the flooding compound between the corrugated aluminium shield and the LDPE oversheath. For buried cables, an inner sheath below the aluminium shield was added to prevent water entry into the core consequent to lightning strikes on the outer sheath. This was designated the *PAP* sheath (polyethylene-aluminium-polyethylene). In areas inhabited by ground-living rodents (for example, gophers) additional protection in the form of a corrugated steel layer was needed resulting in the sheath construction designed *PASP*[5].

In areas with significant termite populations, plain LDPE sheaths are not proof against termite attack and considerable destruction of sheath and insulation can occur. Traditional termite barriers consist of lapped metal tapes held in place by an additional plastic extrusion. Telecom Australia has found a more elegant solution to the problem.

† ASTM—American Society for the Testing of Materials

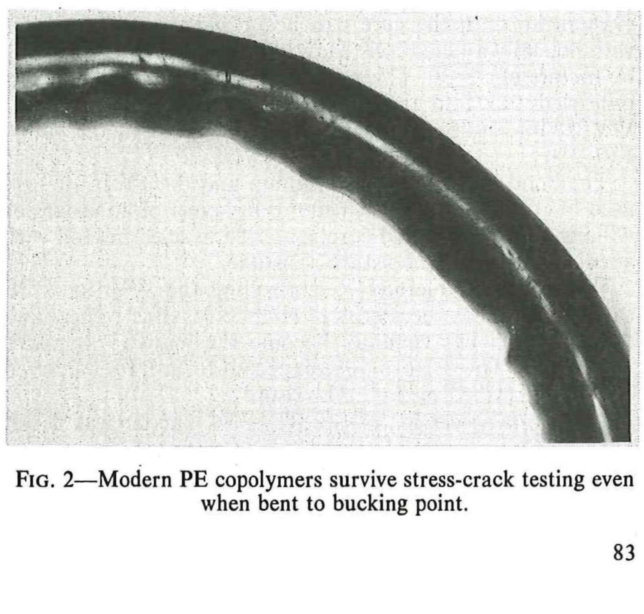


FIG. 2—Modern PE copolymers survive stress-crack testing even when bent to bucking point.

This is to apply a thin oversheath (0·37 mm minimum) of nylon 11 or 12 to a standard LDPE sheath. No successful termite attack on a cable so protected has been recorded over a 10-year period[13].

PE Sheathing—Local Main Cables (Pressurised)

For the protection of humidity-sensitive dry-core cables (that is, mainly pulp/paper insulated), the PE sheath needs not only the mechanical virtues described above, but also a WVPR at least 10 times less than that of plain LDPE. Such improvement is beyond that achievable by tailoring the structure of LDPE, and some composite design of sheath is clearly needed. In the 1940s, Siemens (West Germany) endeavoured to reduce the WVPR of polyvinyl chloride (PVC) sheathed cables by using, beneath the sheath, multiple wraps of soft-bitumen-coated aluminium foil. The result was not particularly successful partly because of the high intrinsic WVPR of plasticised PVC. The principle, however, of putting metal barriers in the diffusion path was basically sound.

In the early post-war years, the shortage of lead and its high price in the USA led Bell Laboratories to develop the ALPETH sheath in 1947. This consisted originally of a corrugated 0·008 inch (0·2 mm) aluminium shield with a bitumen-based flooding compound to seal the overlap in the shield and the gap between the shield and an outer LDPE extrusion. It was recognised that the WVPR of the ALPETH structure was marginal for extended life in wet environments and it was superseded in 1950 by the STALPETH design[14]. This was the first PE sheath incorporating a built-in water-vapour barrier. The construction was as follows. The pulp-insulated core was longitudinally wrapped with an 0·2 mm thick corrugated-aluminium lightning shield, a corrugated tin-lead-plated steel strength member with the seam soldered, a bitumen-based flooding compound, and then oversheathed with LDPE. Perfect manufacture would have resulted in a hermetically-sealed sheath. Any adverse effects or defects in the seam seal were partially nullified by the plugging effect of the flooding compound. The net result was a robust sheath of adequately low WVPR in which the major component was LDPE. This sheath was in production until recently when it was replaced by bonded-barrier designs.

The most elegant method of controlling the WVPR of PE cable sheaths was devised by D. W. Glover of the BT Research Department with the assistance of E. J. Hooker of United Telephone Cables Ltd. (UTC) in 1959[15]. PE-coated aluminium foil is applied to the cable core with the PE surface outwards. During extrusion of the PE sheath, the PE coating welds to the inner surface of the sheath. The result is a bonded aluminium foil, which covers 99% of the inner surface of the sheath. The foil does not inhibit the absorption of the water vapour by the PE, but severely limits the exposed area of PE on the inner surface from which evaporation into the core can occur. Experimental cables with helically applied foils showed reductions in the WVPR by factors of 25–30. The use of longitudinally applied foils improved this into the range 50–100. Current values of WVPR for cables in routine production fall in the range 150–250.

The bond between the aluminium and the PE in the foil used in BT is the result of using thin layers of adhesives or adhesion promoters, and care is needed in selecting foil with adequate long-term moisture resistance.

The BT/UTC method of controlling the WVPR of PE cable sheaths has the merits of simplicity, effectiveness and low cost, and has virtually become the industry standard world-wide. The performance expected from BT's barriered cable is described by J. C. Harrison[16].

An improved version of the BT/UTC barrier was developed by G. E. Clock *et al* in 1963 as a consequence of the development of adhesive copolymers of PE[17] by the Dow Chemical Company. These materials contain 5–8% of copolymerised acrylic acid. When extruded on to metal surfaces, reaction between the free carboxyl groups and oxide layers on the metal surface results in strong chemical bonds. These bonds are permanent on aluminium, slightly suspect on copper[18] and very easily destroyed on lead[19] when exposed to water vapour over long periods of time. The use of foil laminate made with adhesive PE results not only in a strong foil-to-sheath bond, but also improves greatly the bond between the overlapping edges of the barrier. If the barrier foil is smoothed down to give good contact in the overlap before sheathing, reduction factors approaching 1000 can be achieved in the WVPR in routine production.

Whether this ultimate barrier performance is needed depends on factors such as the overall system design and the cable materials used in the core bundle. In France, the aluminium/LDPE sheath on cables used for digital transmission is reinforced by an oversheath of HDPE[20].

AUDIO TRUNK CABLES

Audio trunk cables are short-haul cables that interconnect local exchanges with each other or with long-distance trunk switching centres. Their design is mainly of the quad type and these cables can be regarded as high-quality versions of local main cables.

Because of the conservative approach to changes in the design of cables in critical links in the network, or in those carrying a high density of traffic, changes in audio trunk cables tend to be parasitic on earlier developments in local main cables. Thus, in the UK, the use of PE sheaths with barriers on audio trunk cables followed closely after their appearance on local main cables. The use of cellular MDPE in place of paper also followed its successful introduction into local main cable.

In France, paper has been largely replaced by cellular MDPE, solid LDPE or balloon insulation in a variety of cable types[20]. Until recently, the Bell System used its STALPETH sheath in this area, but it is actively changing to bonded-barrier sheath designs.

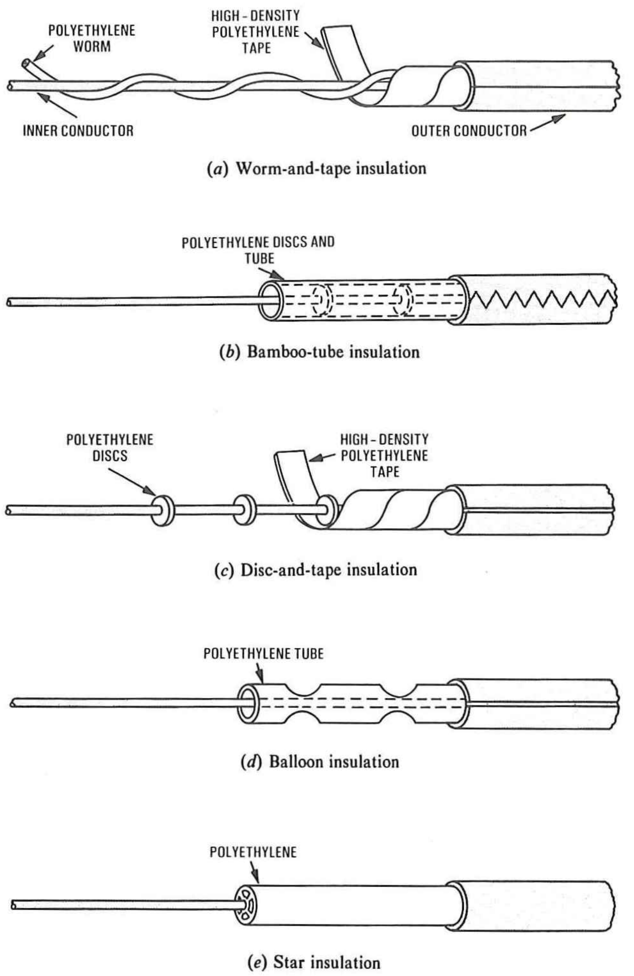
COAXIAL CABLES

Transmission systems consisting of one conductor axially enclosed by another have been investigated since the time of Rayleigh, Heaviside, and J. J. Thompson. The value of the coaxial circuit was not fully appreciated as a high-frequency transmission path, however, until the work of S. A. Schelkunov and colleagues at Bell Laboratories in 1934[21]. Prior to this, coaxial cables had seen only limited use. The very earliest telegraph cables, consisting of a single insulated wire immersed in the sea, were, in effect, coaxial cables with a sea-water return path. Coaxial cables with a metal return path saw limited use as feeders for radio antennas. By 1937, coaxial cables were being adopted as standard on both inland trunk cables and submarine telephone cables.

Land Coaxial Cables

Insulation

Pre-war cables used helical windings of cotopa string, ebonite discs or hard-rubber discs to separate the inner and outer conductors. The first use in the UK of LDPE as spacers occurred in 1946 on the London–Birmingham video link, which used tubes of 0·975 inch (25 mm) diameter. The use of LDPE then spread rapidly into the smaller 0·375 inch (9·5 mm) tubes used in the expanding trunk network of telephone cables. In these 2 sizes of tube, only the discs are present between the inner and outer conductor. With the development of small bore coaxial pairs (4·4 mm diameter) it was felt necessary to have some positive means of preventing conductor short circuits. Various designs have evolved to meet this need and are illustrated in Fig. 3. Type



(*a*) Worm-and-tape insulation

(*b*) Bamboo-tube insulation

(*c*) Disc-and-tape insulation

(*d*) Balloon insulation

(*e*) Star insulation

FIG. 3—Various forms of small-diameter coaxial pair

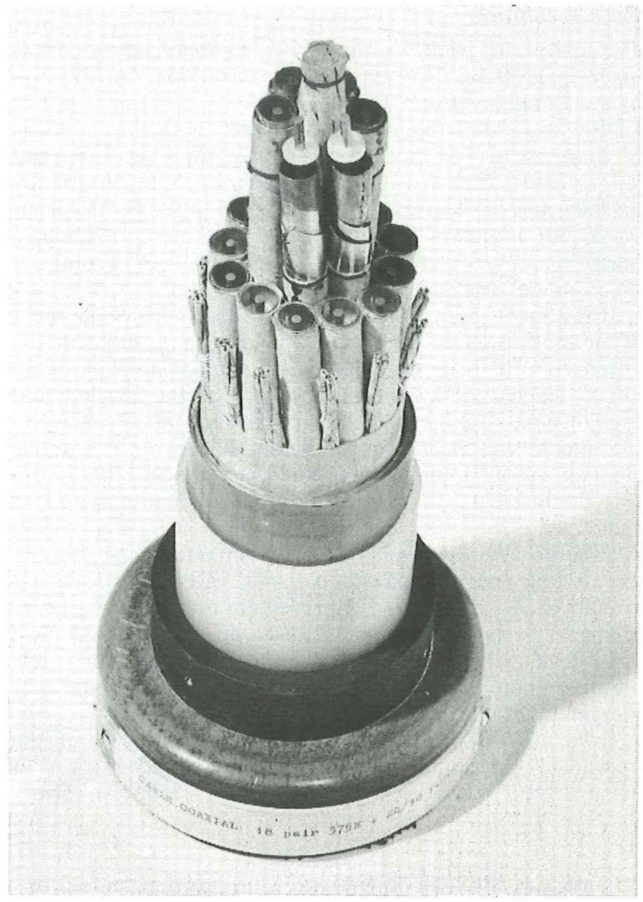


FIG. 4—18-coaxial pair cable showing PE spacers and PE-protected lead sheath.

(*d*) was developed in France by the Societe Anonyme de Telecommunication and is widely used by the French PTT†[22].

Type (*e*) (the star formation) and cellular-PE-insulated coaxial pairs, while extensively used in community antenna television cables, have not found much favour with PTTs for long-distance telephone use. The transmission characteristics of types (*a*)–(*d*) being generally superior[23].

Coaxial pairs of 9·5 mm diameter or similar are now being exploited world-wide to provide bandwidths of 12 and 60 MHz, while the smaller diameter tubes provide 4 and 12 MHz bandwidths.

Coaxial Cable Sheaths

Coaxial cables carry large numbers of circuits. They are usually installed in ducts and are protected by air pressurisation systems. The traditional lead sheath, with plumbed joints, plus protection where necessary in areas of high corrosion risk, has a proven record of reliability. The conservative approach to changes in trunk cable practice means that new developments have to reach an equivalent degree of reliability before being considered.

In the early postwar years, 3 factors inhibited the use of PE on main cables. These were the unresolved WVPR problem, ESCR, and the lack of a proven sheath-closure technique. The first was resolved, in principle, by the Bell STALPETH development in 1950 (not adopted in the UK for reasons of manufacturing economics). It was solved again by the BT barrier-foil technique in 1957. The ESCR problem was fully under control by the mid-1960s. The sheath-closure problem was not adequately solved until the mid-1970s with the development by BT of an injection welding method[24]. It was thus only in the mid-1970s that BT finally abandoned lead on coaxial main cables (with the exception of 60 MHz cables which were engineered in LDPE-protected lead (see Fig. 4)).

In the meantime, experimental thin-lead plus polyethylene sheathed cables were laid from 1951 onwards. Until the early-1960s, however, such constructions were more expensive than either plain lead or thin-lead protected by hessian plus bitumen. In about 1962, when the smaller sizes of lead plus LDPE were becoming economic, a policy decision was taken to use thin-lead plus LDPE on all coaxial main cables. The main reasons were cleanliness in handling and in the duct system.

In the USA, the STALPETH construction provided the Bell system with a good all-round sheath, but even here an LDPE-lead-LDPE construction was in use in 1967 for transcontinental coaxial cables[5]. Lead was generally phased out in 1955–60 in favour of STALPETH.

Submarine Coaxial Cables

These were originally developed for use on short shallow-water links. The 0·62 inch (15·7 mm) Aldeburgh–Domberg cable to Holland, laid in 1937, was a typical example. It provided 16 circuits by means of 2 cables (one go, one return) using carrier techniques without submerged amplifiers. The route length was about 80 nautical miles (150 km) and the top frequency 60 kHz. The insulation used was paragutta (an upgraded compound of gutta-percha containing rubber and paraffin wax).

† PTT—Post, Telephone and Telegraph Administration

Core Insulation

The first use of LDPE in the core of a submarine cable was made in 1939 by the Telegraph Construction and Maintenance Company Ltd. (TCM). The first operational use of LDPE-insulated cable occurred in 1944 with the provision of a series of 15·7 mm diameter unamplified 12-circuit carrier cables for telecommunication links to the Normandy invasion forces. The first 4 cables were gutta-percha insulated, but numbers 5 and 6 from Cuckmere to Dieppe, operational by September 1944, were in LDPE[25]. From that point on, polyethylene was king.

It is a moot point as to the extent of further development of submarine cable that would have been possible in the absence of PE. The development of submarine cable technology since 1945 has been dependent on the development of highly-reliable submerged amplifiers and equalisers using thermionic valves or semiconductor devices as the active element. An example of what could be done with paragutta was the insertion, in 1950, of 4 submerged amplifiers into each of the 2 cables making up the 1937 Aldeburgh–Domberg scheme. This converted a 2-cable 16-circuit link into 2 separate bothway cables providing 60 circuits each—a sevenfold improvement in capacity[26]. There seems to be no doubt that gutta-based cables could have been developed to carry a few hundred circuits for a few hundred kilometres, albeit at the expense of additional submerged plant.

Even at 500 kHz, however, (the top frequency of the upgraded Aldeburgh–Domberg cable) the advantages of using LDPE were clearly apparent[26] (Table 3). Every

TABLE 3
Losses at 500 kHz in 370 km (200 nautical miles) of 15·7 mm (0·62 inch) Diameter Coaxial Cable

Type of Cable	Copper Loss	Dielectric Loss
Parragutta	572 dB	135 dB
LDPE	563 dB	50 dB

LDPE: low-density polyethylene

increase in top frequency above 500 kHz needed to expand circuit capacity, widened the margin in favour of LDPE.

The evolving performance of LDPE-insulated submarine cables post-1950 has been essentially a partnership between the equipment designers in Bell Laboratories, BT and other administrations (France and Japan) and the limited number of LDPE producers interested in the market (mainly ICI and UC). The selection of a PE for a particular system is not a simple matter. For a fixed geometric design, the attenuation of a coaxial cable is affected primarily by the permittivity of the insulant plus a small contribution from the dielectric loss. The relative contribution of the dielectric loss increases as the frequency of transmission increases. Equally as important as choosing the optimum values for permittivity and dielectric loss is the need to keep variations in these 2 parameters within extremely close tolerances. In addition, there are processing requirements that are difficult to define by laboratory tests. The whole selection process is described in detail by S. Matsuoka and L. D. Loan[27]. A selection of submarine cables showing the evolution to those currently providing 4000 and 5500 circuits is shown at Appendix 4.

The largest transatlantic cable, TAT6, completed in 1976, used 8000 t of core insulant (see Fig. 5). The history of the development of LDPE for submarine cable cores is given by Barrie *et al*[28].

Submarine Cable Sheath

The function of the sheath is to provide physical protection

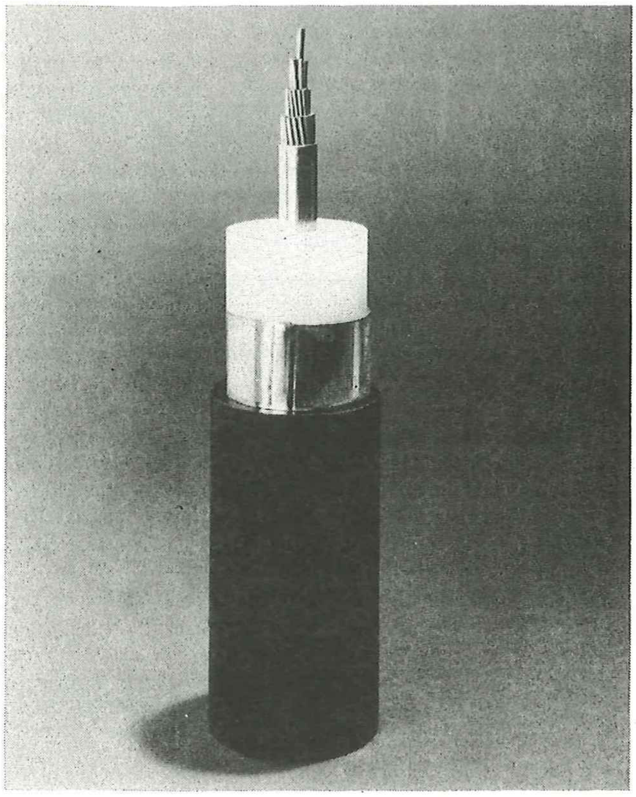


FIG. 5—Submarine coaxial cable (43 mm diameter)

to the core and outer conductor during handling; to provide a hoop stress on the outer conductor to hold it tight against the core to preserve the integrity of coaxial design; and to prevent wrinkling of the outer conductor during bending. In addition, on British cable using an aluminium outer conductor, the sheath has to prevent sea water penetrating the cable.

For cables with aluminium outers, LDPE has proved to be entirely adequate for cables up to 1·5 inch (38 mm) diameter where the cable is just dropped to the sea-bed, either unprotected or with additional wire-armour reinforcement. It is now policy, however, to plough cable into the sea-bed out to the 500 fathom (925 m) line to minimise trawler damage. It has been found beneficial to put a thin oversheath of HDPE on to the unarmoured sections which are to be ploughed. This provides a harder, more abrasion-resistant skin on the cable.

Copper outer conductors are tougher than aluminium, and work-harden quicker. It is not possible to hold down a copper outer with an economical thickness of LDPE and for such cables an HDPE sheath is needed. The main properties specified are mechanical, ESCR, and extrudability[27].

Core and Sheath Restoration Methods

Injection moulding under close control, followed by X-ray examination, is universally used to joint or repair submarine cable cores and sheaths[29]. The resulting joint has a history of excellent reliability.

LAND CABLE SHEATH JOINTING METHODS

Before manufactured cable becomes part of a transmission system, the separate lengths of cable have to be jointed and terminated. Jointing and terminating PE-insulated wire has caused no particular difficulties. However, closing the PE sheath in a totally reliable manner has been a difficult and long-standing problem; the more so because of the relative ease of plumbing lead-sleeve closures on to lead sheaths.

Many tens of methods of achieving closures on PE sheaths have been mooted, tried and abandoned, tried and kept (as better than nothing) or tried and kept as moderately or highly successful; no attempt will be made to describe them all. Joints can be classified under 3 main headings and a few examples of each are given. Because PE cables vary in size (from 1 pair to 4800 pair) and type (fully filled; gas pressurised), several types of joint are needed to cover a whole cable system.

Mechanical (or Gasket) Joints

With mechanical joints, no attempt is made to form a continuous bond between one cable end and the other via the sleeve. The seal between the sleeve (or joint box) and the cable sheaths is obtained by mechanically applied pressure on a soft gasket. Well designed joints of this type are usually fairly successful at a price. They have the advantage that joints can be made irrespective of whether the cables have identical sheaths, and can be readily opened and reclosed when rearranging circuits. The parts needed can be expensive and a wide variety is needed to cover all circumstances. Relaxation of the gasket pressure by creep is a long-term reliability hazard.[29].

Bonded Joints

In bonded joints, a continuous bond is formed from one sheath to the other, but not through an identical material. The inert nature of PE surfaces dictates that special measures to activate the surface are usually essential. The bridging material can be epoxy resin, epoxy putty, hot-melt adhesives, self-bonding tapes etc. Joints of this type have given satisfactory service, but are inevitably operator dependent. The variability that results make them unsuitable for the main network.

Fusion Joints

With fusion joints, the object is to envelope the joint from one sheath to the other with sheath-compatible material. Three techniques have been tried.

Hot gas torch welding is not entirely trouble-free even under factory conditions. Under field conditions the reliability is poor.

Electric-element welding is much less operator dependent than gas welding, particularly where the elements are built-in to the joint sleeves. Highly reliable joints can be produced by this technique, but the method is somewhat inflexible.

Examples of early welded sheath joints are shown in Fig. 6.

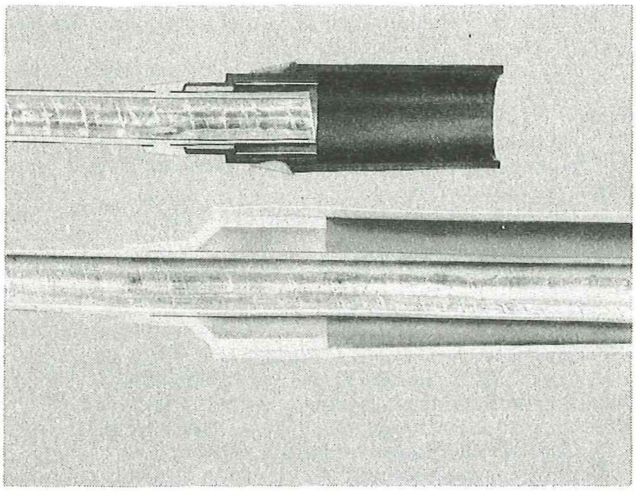


FIG. 6—Early welded sheath joints

Injection moulding has a satisfactory history in submarine cables where the joints are usually simple 1:1 joints of relatively solid structures. Jointing land cables of widely varying diameters with a variety of joint configurations is a more demanding task. The reliability of an injection-welded joint can be made almost operator-independent and good enough for main cable systems[24]. The population of welded-sheath closures in BT's local trunk cables is estimated at 110 000 in 1982 with an annual fault rate per closure of 0·15%. (A closure involves 2 or 3 fusion joints.)

An assessment of some available sheath closure methods is given at Appendix 5.

AERIAL CABLES

Aerial cable can consist of a standard underground cable (intended for duct or direct bury) that is suspended from a messenger wire running from pole-to-pole or building-to-building. Alternatively, a custom-designed aerial cable with an integral suspension strand may be produced. Although PVC has been used for the figure-of-eight sheath, the general choice at present is LDPE.

DROPWIRE

Dropwire is a particular form of aerial cable used to take one or two lines to customers' premises from the nearest overhead feed point. In the UK and the USA, PVC has always been used for the single extrusion that encapsulates the 2 or 3 conductors. The choice is marginal, however, and PE is used by other administrations; for example, HDPE in France.

ECONOMIC BENEFITS

The economic benefits of the availability of PE can be considered under 3 headings.

Primary Capital Expenditure

Where cable using PE as insulant and/or sheath is a direct replacement for a previously used item, easily quantifiable savings in capital expenditure can be determined. For example, a BT study in 1964–65 showed that the replacement of lead cable sheaths on local main and local trunk cables by metal-foil barrier PE resulted in a saving of £0·5M per annum in cable purchasing costs (at 1964 prices). A similar study by Bell Laboratories in 1975 showed that the integrated savings over 1950–1975 resulting from the replacement of lead by PE were approximately $2000M[30].

Replacement of lead by PE also results in a significant reduction in weight (approximately 50% on an average cable of 40 mm diameter). This reduced weight results in a reduction in the cost of transportation between the factory and the customer.

Secondary Benefits due to Reduction in Installation and Maintenance Costs.

The lower weight per unit length and reduced coefficient of friction permit longer lengths of cable to be drawn into ducts. There is a direct saving due to the reduction in the number of joints per kilometre of installed cable (see Fig. 7). A study by BT in 1963 showed that jointing costs decreased by 51% when lead-sheathed cables were replaced by PE-sheathed cable on typical local cable schemes. It was estimated that the saving in capital costs at 1961 prices was £0·275M per 1000 km of cable installed.

A tertiary benefit of reducing the number of joints is a consequential reduction in maintenance expenditure as faults at joints are responsible for a major proportion of underground maintenance costs. It is less easy, however, to untangle these costs saved from the many other factors that impinge on underground maintenance costs; for example, improved sheath-closure techniques.

Similarly, while there is indisputable evidence that PE-

FIG. 7—Long-length cabling saves jointing costs.

sheathed cables suffer fewer faults between jointing points than lead-sheathed cables (because of the absence of corrosion), the exact cost saving is difficult to quantify.

New Facilities

In addition to providing superior replacements for existing designs of pair, quad and coaxial cables, the availability of PE opened up new fields in telecommunications. Vast amounts of PE-sheathed cable are now ploughed directly into the ground at considerable saving in costs over the previous procedures such as full overhead distribution, or lead cable in duct plus protection in corrosion prone areas.

As indicated earlier, it is unlikely that transoceanic submarine cables could have been developed without the availability of high-quality low-loss LDPE. The first transoceanic cable (TAT 1) was laid during a period of rapid world economic development. The instant success of its high-quality telephone circuits between the USA and Europe led to a rapid coverage of the world with advanced designs of ocean cable. This rapid expansion was only moderately affected by the commissioning of public satellite telephone links from the mid-1960s onwards. The troublesome time-delay that results from the use of geostationery satellites still inhibits the provision of all-satellite links between points on opposite sides of the world.

THE FUTURE

In the future, PE will continue to be used for cable sheaths, but its use as a wire insulation material will be affected by the change of transmission medium to optical fibre. The future usage of PE is summarised in Table 4.

TABLE 4
Use of PE in the Future

Current Use	Short-term Prospects	Long-term Prospects
Sheathing of all types	No change	No change
Wire Insulation (local distribution cable)	No change	Some replacement by optical fibres
Wire insulation (local exchange cable)	No change	Some replacement by optical fibres
Wire insulation (local trunk cable)	Some encroachment by optical fibres	Major replacement by optical fibres
Insulation land (long-haul trunk cable)	Early replacement by optical fibres	Complete change to optical fibres
submarine cable (core)	Some reduction in quantity, and relaxation of quality consequent on optical fibres	No further change

CONCLUSION

Two factors have contributed largely to the success of PE in telecommunications. The first is its low cost (the lowest of modern synthetic plastics). This is due to the ease with which crude petroleum is converted to ethylene, and the relative simplicity of the process for converting ethylene into useful polymers. The second is the availability of several different manufacturing processes, which produce materials with a wide range of densities (and hence strengths), and a wide range of copolymers with other olefins; for example, vinyl acetate, propylene and hexene. This versatility enables PE to be finely tuned to the needs of the end product. These factors will also ensure the major presence of PE in future telecommunications practice.

It is virtually impossible to quantify the benefits that industry and commerce have gained as a result of having available a high-quality global telephone service. Telecommunication services are, however, the nerve system of an industrial society and without PE in its various grades, they would be less effective than they are today.

The invention of PE has been, and will continue to be, of major importance in the drive to provide an efficient global telecommunication network.

Acknowledgements

The author would like to thank all those friends and colleagues whose assistance has made this article possible, and the Senior Director, Technology, British Telecom for permission to publish this article.

References

1 GIBSON, R. O. Discovery of Polyethylene. R. Inst. Chem. Monograph, 1964.
2 GIBSON, R. O. *Chemistry and Industry*, 16 Aug. 1980, p. 635.
3 RICHARDS, C. E. BT Research Report No. 9966, Oct. 1939.
4 WILLIAMS. British Patent 514 687.
5 HAYES, H. C. S., and GLOVER, D. W. Inst. Post Off. Electr. Eng. Printed Paper No. 220, 1961.
6 HORN, F. W. Plastics in Telecommunications Cables Conference, Plastics and Rubber Inst., London, Apr. 1967.
7 DODD, G. A. Transmission Aspects of Communications Networks Conference, IEE, London, 1964.
8 ROKUNOHE, M. *Wire and Wire Products*, Aug. 1962, p. 1024.
9 YOSHIDA, *et al.* Plastics in Telecommunications Cables Conference, Plastics and Rubber Inst. London, Apr. 1967.
10 RICHARDS, R. B. *Trans. Faraday Society*, 1946, **42**, p. 10.
11 HOPKINS, I. L., BAKER, W. O., and HOWARD, J. B. *J. Appl. Phys.*, 1950, **21**, p. 206.
12 DECOSTE, J. B., MALM, F. S., and WALLDER, V. T. *Ind. Eng. Chem.*, 1951, **43**, p. 117.
13 CLARK, R. A., and FLATAU, G. *Telecommun. J. Australia*, 1973, **23**, p. 234.
14 ASHBAUGH, R. P. *Bell Labs. Rec.*, Aug. 1951, **29**.
15 HOOKER, E. J., and GLOVER, D. W. British Patent 886 417.
16 HARRISON, J. C. *Trans. J. Plastics Inst.*, 1967, **35**, p. 729.
17 CLOCK, G. E., KLUMB, G. A., and MILDNER, R. C. Twelfth Annual Wire and Cable Symposium, Astbury Park, 1963.
18 WARGOTZ, B. *J. Appl. Polym. Sci.*, 1968, **8**, p. 1873.
19 Unpublished Information, British Telecom.
20 CROS, C., and MARTINEZ, G. Plastics in Telecommunications Conference, Plastics and Rubber Inst., London, Nov. 1974.
21 SCHIKUNOV, S. A. *Bell Syst. Tech. J.*, Oct. 1934, **13**, p. 532.

[22] BIANCHI, A., *et al.* Plastics in Telecommunications Cables Conference, Plastics and Rubber Inst., London, Apr. 1967.
[23] ALLEN, A. F. G. *J. Trans. Plastics Inst.*, 1967, **35**, p. 715.
[24] LOWRY, J. P. A. Plastics in Telecommunications Conference, Plastics and Rubber Inst., London, Sept. 1978.
[25] RHODES, J. *Post Off. Electr. Eng. J.*, Jan. 1946, **38**, p. 136.
[26] WALKER, D. C., and THOMAS, J. F. P. *Proc. IEE.*, 1954, **101**(1), p. 190.
[27] MATSUOKA, S., and LOAN, L. D. Plastics in Telecommunications Conference, Plastics and Rubber Inst., London, Nov. 1974.
[28] BARRIE, I. T., BUCKINGHAM, K. A., and REDDISH, W. *Proc. IEE.*, 1966, **113**(11), p. 1849.
[29] WARD, W. C. Plastics in Telecommunications Cables Conference, Plastics and Rubber Inst., London, Apr. 1967.
[30] MCCALL, D. W. Personal communication, Bell Labs.

APPENDIX 1

Summary of Minutes of a Meeting on 24th August 1937 at ICI (Winnington) between Radley/Richards (BT): Swallow/Perry (ICI) to discuss ALKETH.

STRUCTURE

Alketh is ethylene polymerised to a straight chain paraffinoid hydrocarbon of molecular weight between 5000 and 30 000. X-ray examination shows that the atomic structure is exactly similar to that of paraffin wax. According to the description the molecules are arranged spirally when the material is cast, but may be oriented to a fibrous-like structure by mechanical strain. In this state the material has truly elastic properties but will revert to the 'as cast' condition on heating.

STABILITY

The material is stable up to about 350°C when heated in vacuum. It was stated to be liable to no structural change such as has given trouble with other materials, for example polystyrene.

PROPERTIES

Texture	Similar to gutta-percha
Flexibility	Flexible down to −80°C
Melting point	113°C
Melt viscosity	380 P at 160°C: 188 P at 188°C: 105 P at 240°C
Solubility	Insoluble in most solvents below 60°C
Water absorption	Standard Test Piece 0·025%
Water permeation	0·03 mm film—0·4 mg/in^2/hour/100% RH at room temperature
Tensile strength	2000 lbs per in^2
Extension at break	100% on moulded specimens
Volume resistivity	10^{17} ohms per cm^3
Surface resistivity	10^{14} ohms per cm
Electric strength	1000–1500 volts per mm
Power factor	0·0015 between 50 Hz and 10 MHz

DEVELOPMENT PROGRAMME

Messrs. ICI intend a small experimental output of about 1 cwt per week until the commencement of 1938. They then hope to increase to about 30 tons per year until about the middle of 1939, after which 250 tons per year would be possible if all goes well. They intend at first to market the material at a high price (comparable to that of polystyrene) and seek a use in the high frequency telecommunications field. Potentially, however, Alketh is a cheap dielectric as the raw material is inexpensive and no complicated mechanical syntheses are involved. Eventually, the price should be reduced to that of a cheap phenol-formaldehyde.

INTEREST TO THE DEPARTMENT

Messrs. Swallow and Perry were interested in the possible use of the new material by the Post Office, and apart from wire coverings, for which without a textile protection it seems too fragile, the following applications were discussed with them.

(1) Use as an insulating or spacing material in high frequency equipment generally, for example coaxial cables.
(2) As a sheathing material substituting lead on telephone cables, when price is sufficiently reduced. The material may prove too 'tender' for this and water transmission requires further investigation.
(3) Coil Impregnation.

Having regard to its permittivity, power loss and general physical properties, Alketh also seems promising as a submarine-cable dielectric replacing guttapercha derivatives.

PROPOSED INVESTIGATION

Samples are being obtained from ICI and it is proposed to initiate a Research Case.

APPENDIX 2

Description of BT Cellular PE-Insulated Local Exchange Cables

Parameter	Copper Conductor	Aluminium Conductor
Number of pairs	50–4800	50–2000
Wire diameter	0·32–0·9 mm	0·5 mm
Cellular insulation		
Radial thickness	0·19–0·45 mm	0·2 mm
Ultimate tensile force	0·7–3·5 N	1·0 N
Sheath	LDPE (with barrier)	LDPE (with barrier)

APPENDIX 3

Improvements in the Properties of Sheathing-Grade LDPE 1950–1980

In 1950, the LDPE in use was specified only by its melt flow index (MFI) of 7, compared with grades currently available with MFIs in the range 0·1–0·3. Over this range of MFI (from 7 to 0·3 and below), the most important change has been the resistance to environmental stress cracking. When subjected to the ASTM 1693 test, MFI 7 material cracks in a few minutes in n-propanol; in concentrated detergent it cracks virtually instantaneously. Ethylene vinyl acetate and other copolymers, which are virtually uncrackable in concentrated detergent, are now available. It is still regarded as good practice to specify a detergent test on bent cable to check that degradation during processing has been kept under control.

APPENDIX 4
Submarine Cable Development

Date	Cable System	Diameter (inches)	Length (km)	Number of Repeaters	Top Frequency	Number of Circuits
1945	UK–France	0·62 (15·7 mm)	130	Nil	60 kHz	12
1947	UK–Holland	1·7 (43·3 mm) (air spaced)	155	Nil	804 kHz	84
1950	USA–Cuba	0·46 (11·7 mm)	230	3+3 (2 cables)	108 kHz	24
1954	UK–Norway	0·935 (23·7 mm)	566	7	352 kHz	36
1954	USA–Caribbean	0·62 (15·7 mm)	1850	14+ 7 land	150 kHz	Mixed data and telephony
1956	First ocean crossing UK–USA (TAT 1)	0·62 (15·7 mm)	3600	(2 cables) 51+51	164 kHz	36
1961	UK–Canada (CANTAT 1)	0·99 (25·1 mm)	3860	90	608 kHz	80 (4 kHz)
1963	UK–USA (TAT 3)	1·0 (25·4 mm)	6510	183	1·05 MHz	138 (3 kHz)
1967	UK–Jersey	0·99 (25·1 mm)	253	18	4·8 MHz	480 (4 kHz)
1970	USA–Spain (TAT 5)	1·5 (38·1 mm)	6352	361	5·9 MHz	845 (3 kHz)
1971	UK–Germany	1·5 (38·1 mm)	525	45	14 MHz	1380 (4 kHz)
1974	UK–Canada (CANTAT 2)	1·5 (38·1 mm)	5180	473	14 MHz	1840 (3 kHz)
1976	France–USA (TAT 6)	1·7 (43·3 mm)	6283	694	30 MHz	4000 (3 kHz)
1977	UK–Belgium No. 4	1·47 (37·3 mm)	104	22	45 MHz	3900 (4 kHz or 5520 at 3 kHz)

APPENDIX 5
Sheath Closure Methods

Country	Description	Principle	Field of Use	Remarks
		LOCAL DISTRIBUTION CABLE		
UK	Shrink-down sleeve	Bonded	In-line T-joints	Effective, flexible, reliable but operator dependent
	Sleeves 31A	Gasket	Radial distribution from 100- and 50-pair cables	Easily re-opened
West Germany	Siemens TK clamp sleeve	Gasket	All types	Simple, effective, low-cost easily re-opened
Japan and Australia	Splice case plus encapsulant	Encapsulation	All types	Effective, but expensive and not re-openable
USA (Bell)	Splice case	Gasket	Most joints are above ground—splice case used when needed.	Effective, re-openable but expensive, inflexible
		LOCAL EXCHANGE MAIN CABLES LOCAL TRUNKS		
UK	Epoxy-putty wipe	Bonded	All types	Very flexible, inexpensive, operator dependent. Reliability approximately equal to plumbed-lead joint—obsolescent
	BICC injection weld	Fusion	Local trunk only	Very reliable, operator dependent, not flexible enough for local main cables
	BT injection weld	Fusion	All types	Very reliable, minimum of operator dependence, flexible
West Germany	Siemens electrical weld	Fusion	All types	Very reliable, minimum of operator dependence
USA (Bell)	Splice case	Gasket	Most joints are above ground—splice case used when needed.	Effective, re-openable, expensive, inflexible
		TRUNK COAXIAL CABLES		
UK	BT injection weld	Fusion	All types	See above
West Germany	Siemens electrical weld	Fusion	All types	See above
USA (Bell)	Splice case	Gasket	All types	See above

British Telecom and Project UNIVERSE

G. H. L. CHILDS, PH.D., M.SC., and G. MORROW, M.SC., C.ENG., M.I.E.E†

UDC 681.3 : 621.396.946

This article briefly outlines the factors that are influencing the emergence of local area networks (LANs) and describes British Telecom's involvement in Project UNIVERSE—an experiment to provide high-speed data links between several LANs in different parts of the UK by using the Orbital Test Satellite.

INTRODUCTION

Local area networks (LANs) were developed as a means of providing interworking facilities for processors and peripherals, including terminals. A limitation with conventional LANs is that they are confined to a relatively small geographical area. In order to investigate the facilities required for interconnecting LANs on a national or even an international basis, British Telecom (BT) is participating in the UNIVersities Extended Ring and Satellite Experiments (UNIVERSE).

This article briefly discusses the future utilisation of LANs and how Project UNIVERSE is helping to identify the requirements for interworking such distributed systems.

LOCAL AREA NETWORKS

During the past few years, the LAN has emerged as a new type of data communications equipment[1], permitting powerful computing facilities to be established with the LAN acting as the communications infrastructure. It is now possible to build a processing centre in a modular fashion so that facilities can be duplicated to add computing power and service reliability; new facilities can be added without the existing service being affected; and the functions of the centre can be split between units attached to the LAN. It is therefore possible to optimise the individual units for specific functions (compilation, execution, database, message services, etc).

This trend towards distributed processing is both generating demand for local networking, and receiving impetus from the capabilities that LANs offer. Because LANs permit rapid data transfer (usually in excess of 1 Mbit/s useful data rate), it is possible to cater for the high peak data rates required when a processor and the database it is processing are separated by a LAN. Application processes are able to continue running at nearly full speed and are not suspended during lengthy data transfer periods.

In the next few years, especially during the work leading to the fifth-generation computer, the development of a new situation where a large number of specialist computer centres are brought on stream can be expected. These will be based on LAN communications and will be designed to provide certain services for the organisations that build them. The scene is then set for still more powerful computer applications to be developed by linking these centres so that new and sophisticated processing can draw support from the community of specialist building blocks available on a national (or international) basis.

The exact manner in which this will happen is difficult to judge at this time; however, examples can be suggested. In the development of the fifth generation computers themselves, highly complex integrated-circuit systems will be needed. The design support made available to the engineers working on this project must include the application of computer-aided design to large-scale integrated circuit devices and system simulation capability. Both of these applications are demanding computer tasks, which may develop in different parts of industry, and which would need to be drawn closely together to reach successfully the level of capability that these new tasks require.

This extended distributed computing concept places the same demands for the communications between the LANs as those required in transmission across them. For processing to be possible in realistic times, it will be necessary to transmit 'bursty' data traffic loads with very high peak transmission rates. There are several different ways of achieving, for example, terrestrial communications links, including radio, optical fibres and cable, and the orbital satellite links that are the subject of the experiments reported in this article.

INTERCONNECTION OF LANS USING SATELLITE LINKS

A number of experiments are taking place at the moment concerned with using orbital satellites to link LANs. Of particular interest are the NADIR experiments in France[2] and Project UNIVERSE in the UK. There is also some work in progress in the USA on a Wideband Satellite Experiment, though this is orientated more towards voice transmission than the more general LAN communications being provided by UNIVERSE and NADIR.

Project UNIVERSE is being funded by the Department of Industry, Science and Engineering Research Council (SERC), BT, GEC-Marconi and Logica and was started in 1981. The aim of the project is to investigate the facilities that must be developed for allowing data communication over a concatenation of terrestrial and satellite networks with particular emphasis on the use of Cambridge Rings for local distribution within the individual establishments.

The various activities of Project UNIVERSE are as follows.

(*a*) To use the Orbital Test Satellite (OTS) to develop a high performance network for linking a number of LANs located in different parts of the UK. This main network is supported by an auxiliary network conforming to CCITT† Recommendation X25.

(*b*) To measure the performance of the network components for the types of traffic likely to be encountered in practice.

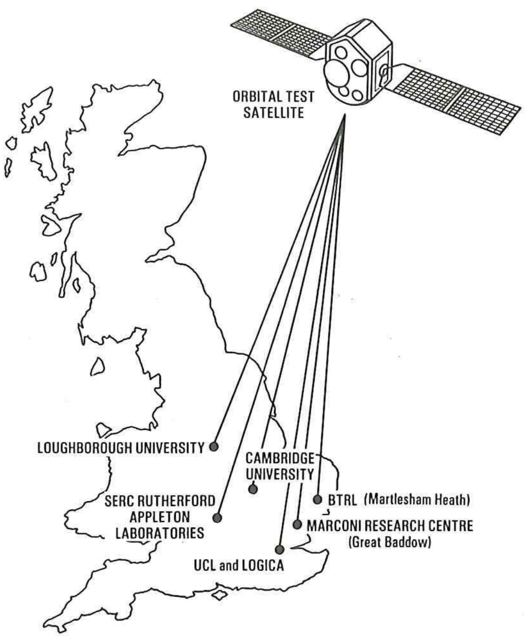
(*c*) To develop procedures to ensure the utility of the system for computer–computer and terminal–computer operation.

(*d*) To investigate the utility of high-speed LAN and satellite links for business and computer communications. (This is being assessed by running a series of typical applications on the network.)

(*e*) To develop more appropriate components and bridges for optimising a system of this type.

† Research Department, British Telecom Major Systems

† CCITT—International Telegraph and Telephone Consultative Committee.



BTRL: British Telecom Research Laboratories
SERC: Science and Engineering Research Council
UCL: University College, London

FIG. 1—Participants in Project UNIVERSE

The current experiment has 7 partners as shown in Fig. 1. There are 4 components to the communications systems:

(*a*) the satellite system, which provides the main wide area network (WAN) for the experiment at a 1 Mbit/s transmission speed;

(*b*) the Cambridge Rings, which provide the LAN facilities in each of the partners' premises;

(*c*) the high-speed terrestrial link which uses a BT underground transverse-screen cable connecting University College, London (UCL) and Logica (which does not have its own OTS data communications and relies on the UCL's link to relay its data into the UNIVERSE network); and

(*d*) the X25 network using BT's Packet SwitchStream data network, which provides a secondary WAN capability, operating at a 9·6 kbit/s transmission speed.

The various networks are connected together by a number of gateway components.

(*a*) A satellite data terminal bridge provides communications between a local Cambridge Ring and the OTS. This equipment has been developed by Marconi Communications Systems Ltd. (MCS) and is described in more detail in another article[3] in this issue of the *Journal*. However, the installation at British Telecom Research Laboratories (BTRL) is unique, in that it uses a 2 Mbit/s data modem designed by BTRL.

(*b*) A ring–ring bridge provides communications between local rings.

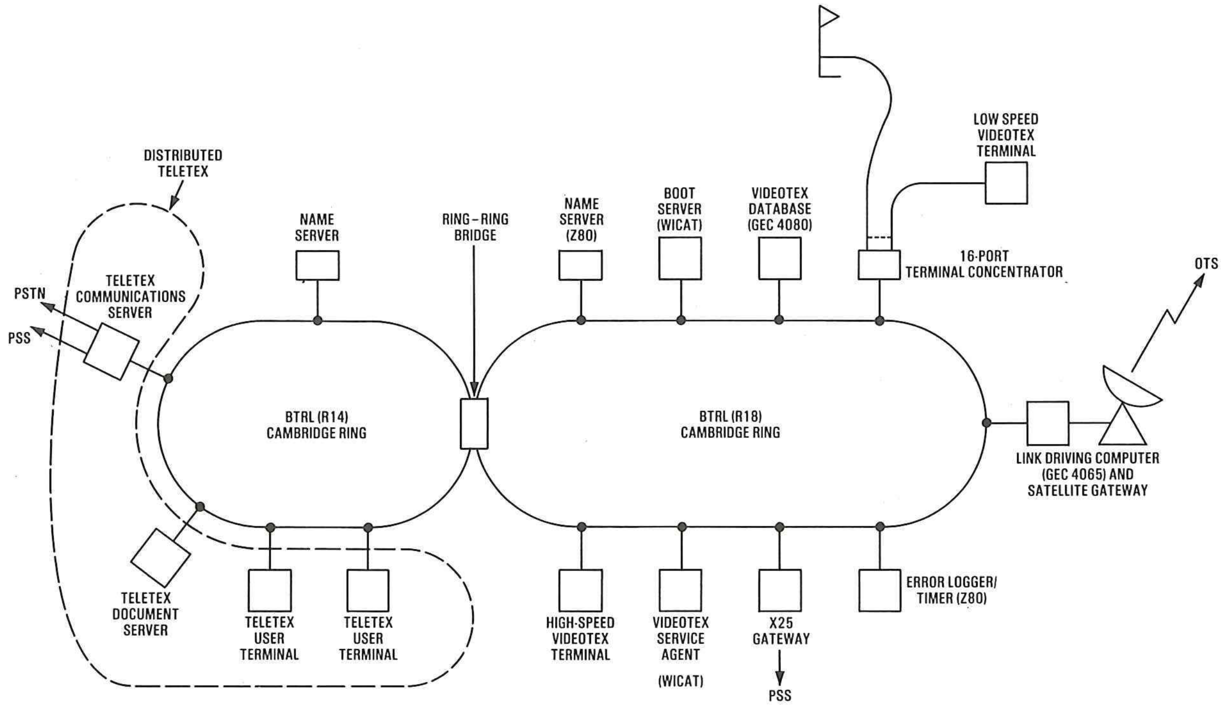
(*c*) An X25 gateway provides communication between a ring and the X25 network.

(*d*) A terrestrial half-bridge provides communication between a ring and the high-speed terrestrial link.

BRITISH TELECOM'S INVOLVEMENT

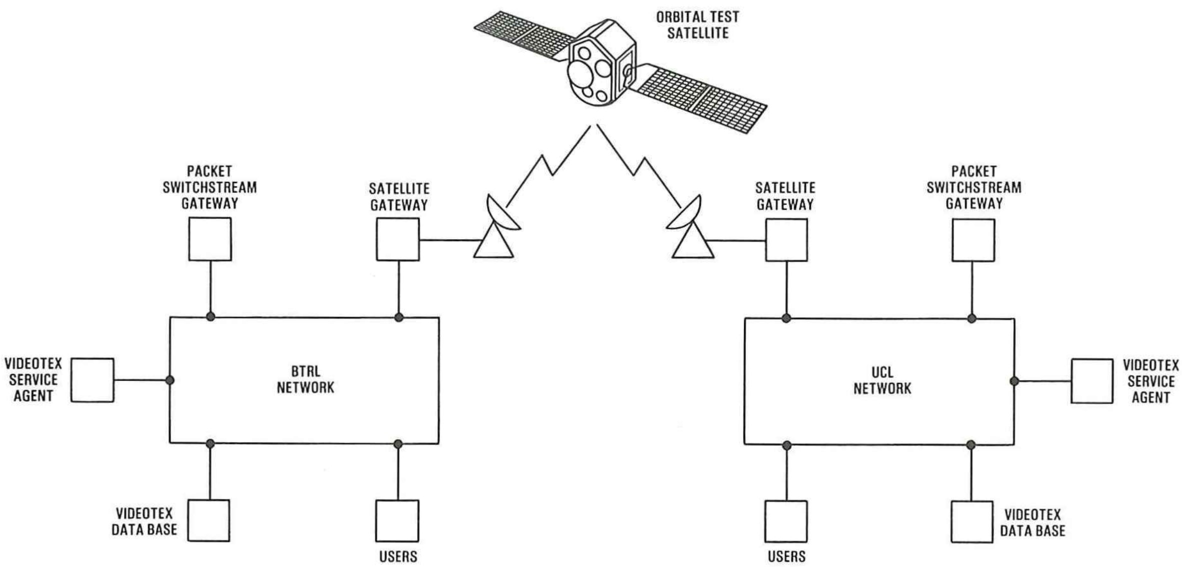
BT has been an active participant in Project UNIVERSE; its staff has assisted in planning the experiment, the infrastructure of the network and the operating protocols. The ground stations, built by MCS, have been provided by BT, together with access to the transponder on the OTS. In addition to assistance with the provision of the network infrastructure, BT has also been working on an experimental programme using the network. A LAN, based on 2 interconnected Cambridge Rings at BTRL, Martlesham Heath, has been installed, and experimental systems for distributed Videotex and Teletex are being developed.

A standard Prestel Videotex system running on a GEC4080 processor (the range of computers used to provide the Prestel public service) has been successfully connected to the Cambridge Ring. Videotex terminals attached to the ring (or other parts of the UNIVERSE network) can thus access a special UNIVERSE Prestel system. The next stage



OTS: Orbital Test Satellite PSS: Packet SwitchStream PSTN: Public switched telephone network

FIG. 2—BTRL network configuration for Project UNIVERSE



BTRL: British Telecom Research Laboratories UCL: University College, London

FIG. 3—Videotex system architecture

will be to implement further databases in the network, and Videotex service agents, which will help users to find the specific host that holds the information they wish to refer to. BT's partners in this are UCL. This work, while using Videotex formatted databases, is being undertaken to gain actual experience in the problems of distributed database maintenance and access in general.

Work is also underway to connect a Teletex server to the local network at Martlesham. This work will give BT an opportunity to experiment with a distributed Teletex system in which terminals, server and Teletex network gateways are physically separated by the LAN. With this system, Teletex documents will be exchanged between BTRL, UCL and Logica to check on the compatibility of these Teletex implementations.

The configuration under development at BTRL is shown in Fig. 2; the proposed distributed Videotex experiment is shown in Fig. 3.

THE NEXT STEP

A great deal of effort has been put into the establishment of the UNIVERSE network, and the experiments that have been mounted on it. It is hoped that a second phase of work can be undertaken (UNIVERSE II) in which a powerful terrestrial network based on BT's MegaStream service at 2 Mbit/s will be added. It is expected that the OTS will be shut down at the end of 1983, and consideration is being given at present to possible alternative satellite communications based on a new satellite data terminal (currently being designed by MCS to operate at 8–10 Mbit/s).

If this second phase of the project goes ahead, BTRL's experiments on Videotex and Teletex will be continued and refined.

References

1 ROWLANDS, M. G. Local Area Networks. *Br. Telecommun. Eng.*, Apr. 1983, **2**, p. 6.

2 HUITEMA, C., and RADUREAU, J. Interconnecting Local Area Networks through Satellite Links. International Conference on Computer Communication. London, Sept. 1982.

3 ACKROYD, B. R. Project UNIVERSE—Local Area Networks and Satellite Communications. *Br. Telecommun. Eng.* July 1983, **2**, p. 121.

Book Review

Electric Circuit Theory. R. Yorke. Pergammon Press Ltd. xvii + 331pp. 146 ills. £13·00 Hardback; £6·50 Paperback.

This book is a useful presentation of material which forms the basis of a weekly 1 hour course in electric circuits taught to undergraduates of Southampton University, although some of the topics have been expanded.

The subject matter broadly includes DC and AC circuits and networks, steady-state and transient analysis of linear circuits using the exponential and Laplace transforms, circuit analysis and network topology, and frequency response loci and Bode diagrams. Perhaps of less relevance to telecommunications undergraduates is the inclusion of a chapter on polyphase power circuits.

The text includes nearly 100 worked examples and over 100 graded questions, ranging from the relatively simple to first-year university examination standard.

It is a well-written and easily-read book, but no concessions have been made on the mathematical ability required by readers to understand or tackle the questions set in the text. Prospective readers should have mathematics to GCE A-level standard and an ability in calculus, complex numbers, matrices and determinants.

The book should be a useful extra text for undergraduates, but is not strictly relevant to those students not studying in universities or polytechnics.

E. A. HACKETT

Sceptre 100—A Microprocessor-Controlled Facility Telephone

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UDC 631.395.721.1: 681.31–181

Sceptre 100 is an all-electronic telephone which uses a microprocessor to offer new facilities to customers of British Telecom. The history of its design and development by British Telecom Research Laboratories, with some details of its operation, are described in this article.

INTRODUCTION

In 1982, 3 new telephones were added to British Telecom's (BT's) standard range. Two of these, Viscount and Statesman, have already been described in this *Journal*[1,2], as has the *raison d'être* of electronic telephones versus those based on traditional principles[3]. Sceptre 100 (Telephone No. 10 001R) differs from the other 2 telephones in that it offers facilities to the customer over and above basic press-button telephony. In particular it provides as standard: last-number redial, 10-number storage (10-address repertory), 8-digit liquid-crystal display (LCD), call timer, real-time clock, earth recall, and access-pause facility, the last 2 of which are for PBX use. The LCD allows the customer to see the number being dialled, the contents of the memory stores, the time of day or the elapsed call time. Battery condition is also shown by an indicator on the left of the LCD.

Central to the operation of Sceptre 100 is a 4 bit microprocessor which executes the necessary logic and control functions. The use of modern integrated-circuit (IC) techniques enables Sceptre 100 to be physically small; it is approximately half the weight and height of the Telephone No. 746 (see Fig. 1).

PROJECT HISTORY

In 1979, the question was asked, 'What, if any, are the advantages of using a microprocessor to replace the dialling IC in a telephone set?' The answers were threefold:

(*a*) Additional facilities could be provided for the customer, improving and possibly increasing his use of the telephone.

(*b*) The combination of facilities could be changed relatively simply and cheaply by developing a new program, overcoming most of the overheads associated with custom or semi-custom IC designs.

(*c*) The cost of implementation would be less than that of providing the same facilities by other techniques, and the route to production would be faster. Indeed, at that time, large-volume microprocessors like the Texas Instruments TMS 1000 cost less per unit than some available dialler chips, although their p-channel metal-oxide-semiconductor (MOS) technology rendered them unsuitable for direct inclusion in a facility telephone.

A programme of work was therefore undertaken in which a currently-available microprocessor, the Intel 8748, was programmed, and circuits designed, to make British Telecom Research Laboratories' (BTRL's) first microprocessor telephone, known as *Microtel I* (see Fig. 2).

The case was designed in-house and was made from fibreglass. The telephone had a 12-digit light-emitting diode (LED) display, 4 number stores, last-number redial, a call timer and a programmable tone caller. The last feature was a result of the microprocessor being used to generate the tones, enabling their pitch, alternation rate and volume to be changed from the keypad with the telephone in the ON-HOOK condition. Other versions giving different facilities were also made, including one which was capable of receiving information from the exchange, such as advice of call cost,

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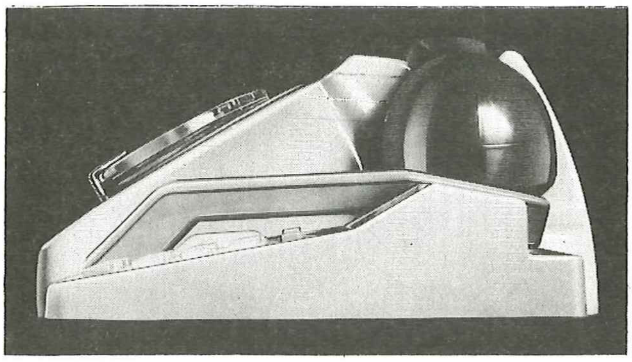


FIG. 1— A comparison of Sceptre 100 and Telephone No. 746 profiles

FIG. 2—Microtel I, BTRL's first microprocessor-controlled telephone

in association with an experimental bi-directional signalling system. Unfortunately, the telephone was limited by the technology. The n-channel MOS technology used for the microprocessor, together with an LED display, meant that approximately 200 mA was needed to operate fully the logic; this current was considerably in excess of the 1 mA that could be safely diverted from the line current applied to the speech circuit. A calculator-type power supply was necessary, even for basic telephony, which was considered unsatisfactory for a production instrument.

A complementary metal-oxide-semiconductor (CMOS) version of the TMS 1000 microprocessor was announced by Texas Instruments, and BTRL commissioned a program which would provide a sub-set of the facilities offered by the 8748-based instrument. A Microtel I case was used to house circuitry containing the TMS 1000C (see Fig. 3). The telephone offered press-button dialling in either 10 pulses/s loop-disconnect or multi-frequency (MF4) signalling, selected by an internal switch; last-number redial; a programmable tone caller; and a single-number store, which could also be used as a notepad facility. The last feature enabled the user, during a conversation, to store in the memory a number which he wished to dial later; for example, for directory-enquiry calls. The use of CMOS technology meant that the *Microtel I/TMS*, as it was called, was wholly line powered, a capacitor enabling the stored number to be retained for 30 min if the telephone was disconnected.

FIG. 3—Microtel I/TMS, BTRL's first telephone containing a CMOS microprocessor

It was realised at an early stage that provision of a display was an extremely useful facility on a telephone with repertory because it enabled stored numbers to be checked without the need to dial them. LCD technology is the logical choice for line-powered telephones because of their very low current consumption, and so the search continued for a microprocessor offering a ready LCD interface.

One such microprocessor became available from ITT Semiconductors, the SAA 6002; this was pre-programmed to give facilities similar to those conceived for Microtel I (display version), but had a slightly different operating protocol for memory operations, and an extended number of stores. This CMOS microprocessor was able to drive an LCD directly from its output pins and consumed only 60 μA.

Meanwhile, in-house case design had progressed, anticipating the use of LCDs (see Fig. 4). This new case was brought together with a circuit incorporating the SAA 6002, and known locally as *Microtel II*, to produce a model for the open week at BTRL in 1980. The case and handset parts were again produced by fibreglass/resin lay-up techniques, and the circuit was designed from the knowledge gained during the Microtel I programme.

Considerable interest in this telephone was generated during open week and, as a result of a formal tendering exercise, a contract for 20 000 instruments was let in July 1981 with Denis Ferranti Meters Ltd. The serious work of translating the one laboratory model into a telephone suitable for large-scale production then commenced.

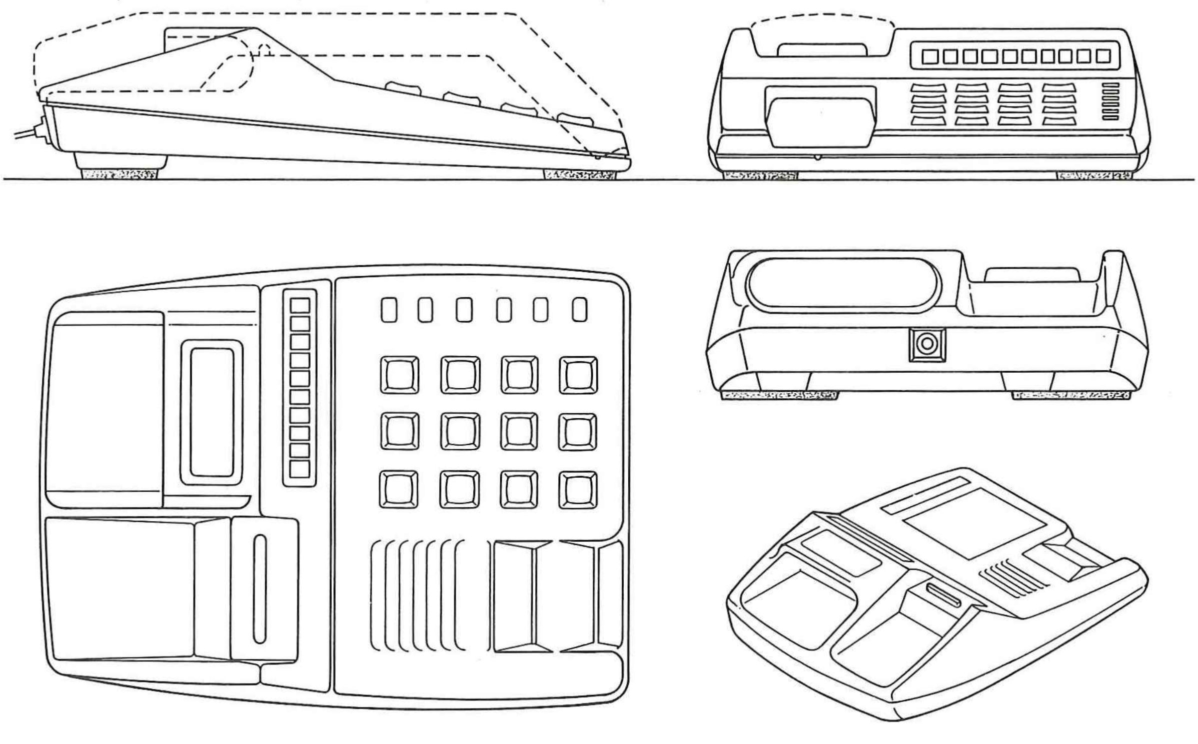


FIG. 4—Early Sceptre 100 case drawings

It was necessary to establish a close relationship with the contractor and sub-contractors to ensure speedy and effective transfer of ideas and information. Among the parts which needed to be redesigned or refined were the case top and base, handset, gravity-switch mechanism, keypad components, printed-wiring board (PWB) and LCD.

First mouldings were received 17 weeks after the date of contract, and pilot production commenced in April 1982. Microtel II was given the marketing name *Sceptre 100*. Because of the high customer demand, the contract with Denis Ferranti Meters Ltd. was extended in July 1982, and a second manufacturer, A. P. Besson Ltd., received a contract in December 1982. Sceptre 100 is currently being offered in 2-tone beige and 2-tone blue, with 3 other colours due to be introduced later this year.

PHYSICAL AND MECHANICAL DESIGN

The Case

Sceptre 100 was designed to have the smallest size in the horizontal plane commensurate with the size of its 3 main external features: the keypad, the LCD and the handset recess. These were in turn related to the number of buttons, their spacing, the number of legible digits on the LCD and the handset size. The latter is largely dictated by the size of human heads[4]. Placing the handset over the keypad and LCD was not advisable for Sceptre 100 as this would impede keypad and display operations with the handset in the ON-HOOK position. Regard was taken of the need for reasonable ease of assembly and good aesthetic features. In order to minimise its visual intrusion on a desk, the overall height of Sceptre 100 was kept as small as possible. A keypad angle of 10° was used, which correlates well with the human-factors findings for the best manual angle, although the best visual angle for the keypad is somewhat larger than this[5]. Account was therefore taken in the design of buttons and legends to help to compensate. The LCD also shares the 10° angle as it is secured to the logic PWB, which contains the keypad; in this way multiple interconnections are avoided.

Fig. 5 shows a production Sceptre 100, and it can be seen that the top of the hand-hold, to the rear of the LCD, follows the handset split line at the receiver end. Under the handset are the gravity-switch actuator, BT logo, number label and raised monticulus, a feature introduced to complement diagonally the handhold/display area and to assist handset 'walk-on' (the ability of the handset to settle down into the gravity-switch operated position when carelessly replaced).

The overall case design is a compromise between square and rounded design, with a 1·5 mm edge radius used wherever possible. The case is an injection moulding in acrylonitrile/butadiene/styrene (ABS).

FIG. 5—A production Sceptre 100

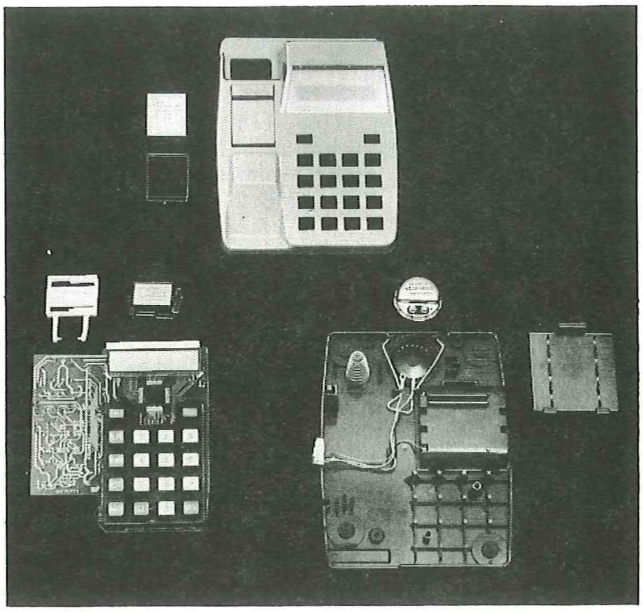


FIG. 6—The major components in the case

The base, also an ABS moulding, supports the PWB and contains the battery compartment and tone-caller transducer; it is fixed to the cover by 3 screws. Interior detail of the base can be seen in Fig. 6. Multi-point reinforcement is provided under the keypad to minimise PWB flexure when the press-buttons are subjected to excessive operating force. The logic PWB is retained by 2 screws and a clip. A wire retainer holds the tone-caller transducer in its acoustically-designed housing. The 4 primary cells can be accessed externally, a 10p coin being used to remove the battery cover. Labyrinths ensure that the handset and line cords cannot be withdrawn from the case by pulling.

The Handset

The handset, which is constructed in 2 halves held together by pegs, snap fastenings and a single screw, houses the microphone, receiver and transmission circuit (see Fig. 7). The handset is moulded from ABS and has internal ribs to add strength and mechanical rigidity. The transducers are held in place by spring clips, additional pressure being

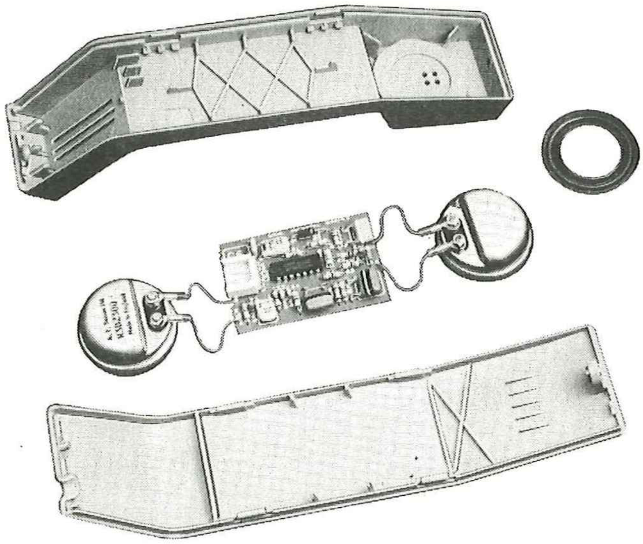


FIG. 7—Major handset components

provided by a foam pad to seal the receiver and Trimphone-type W washer to the earcap. Self-adhesive foam seals the microphone to the handset moulding and gives isolation from mechanical shock and vibration.

The assembled handset is light (160 g) and easy to hold, and the earcap, or pinna plate, is designed to give a good seal to the ear; the latter factor contributes to good transmission performance. The central 27 mm of the earcap, excluding the orifice detail, is of spherical form, facilitating testing on artificial-ear apparatus.

The Keypad

Sceptre 100 has 18 buttons on a 4 × 4 matrix with 2 smaller keys above. The 0–9, or digit, buttons are distinguished from the function buttons by being moulded in a lighter colour. Each button is a 2-shot injection moulding in ABS, comprising an inner, which carries the legend, and an outer. All the buttons are housed in a glass-filled modified-polyphenylene-oxide (Noryl) injection-moulded frame, which guides them as they are depressed onto the silicone elastomer membrane. The membrane comprises 18 bells of double-chamber construction, designed to give a collapse action (see Fig. 8), in common with other modern electronic telephones. The conductive-rubber pill inside the lower chamber bridges interdigitated gold-plated contacts on the PWB, forming a low-impedance crosspoint between row and column connections. The upper chamber provides overtravel after contact has been made, helping to avoid contact bounce.

As the recall switch is required to pass up to 200 mA, it is a separate microswitch with a specially-designed actuator, operated by the elastomer membrane through a hole in the PWB.

ELECTRICAL CIRCUITRY

Transmission Circuit

The transmission circuit comprises a single IC, the SGS LS285, with 23 small additional components to perform the functions of send amplifier, receive amplifier, sidetone balance, variation of gain with line current (regulation) and control of telephone impedance.

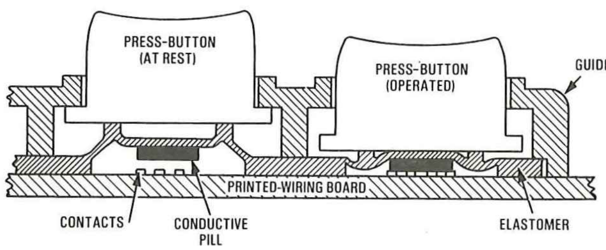


FIG. 8—Section through keypad element

The principles of operation of the transmission circuit can be appreciated by reference to the bridge configuration shown in Figs. 9(*a*) and 9(*b*). The need to control sidetone adequately has been discussed previously[6]. Low sidetone is especially important on connections with a high loss.

For a condition of minimum sidetone in the circuits of Figs. 9(*a*) and 9(*b*), the following relationship is true:

$$\frac{Z_L}{Z_1} = \frac{Z_B}{Z_2},$$

where Z_L is the line impedance seen by the telephone;
Z_B is the sidetone balance impedance; and
Z_1 and Z_2 are circuit impedances, usually resistive, used to determine the ratio of Z_L:Z_B.

While it is not possible to minimise sidetone for all connections, the criterion used in designing the Sceptre 100 circuit required that sidetone level should tend to zero when Z_L took the form of the network shown in Fig. 9(*c*).

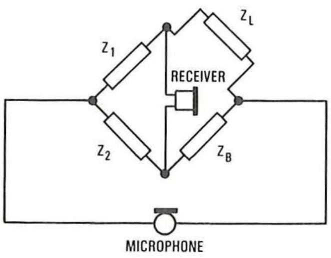
The transmission circuit is connected via sensitivity-determining resistors to the rocking-armature transducers. Rocking-armature technology was chosen for the receiver because it represented a proven and reasonably economic solution and, for the microphone, because to have developed a solution based on an alternative technology would have been outside the timescale originally conceived. Despite the acceptable performance of the rocking-armature microphone, it is felt that a microphone based on electret principles would have conferred distinct advantages on the design by giving greater insensitivity to mechanical noise, and a better control of frequency characteristics. A consideration of the merits of electret microphones as replacements for carbon transmitters has been made previously[7].

Logic Circuit Design

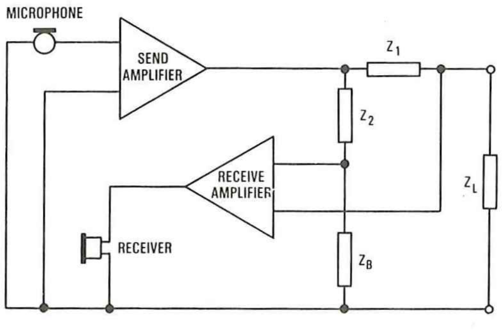
The maximum current that a telephone instrument is permitted to take continuously from the line is presently 20 μA. This precluded Sceptre 100 from being designed to operate solely from line current, as the logic circuit consumes approximately 80 μA. Added to this was the requirement to retain the memory and keep the microprocessor running, maintaining clock time when disconnected from the telephone line. Battery back-up was thus essential. From reported experience, nickel-cadmium batteries were rejected on the following counts:

(*a*) an operating life of only 3–5 years;

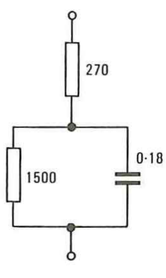
(*b*) the requirement for a charge switching unit, which disables charging during telephone use or line disturbances



(*a*) Basic bridge circuit



(*b*) Bridge circuit applied to telephone



(*c*) Z_L for zero sidetone

FIG. 9—Telephone bridge circuitry

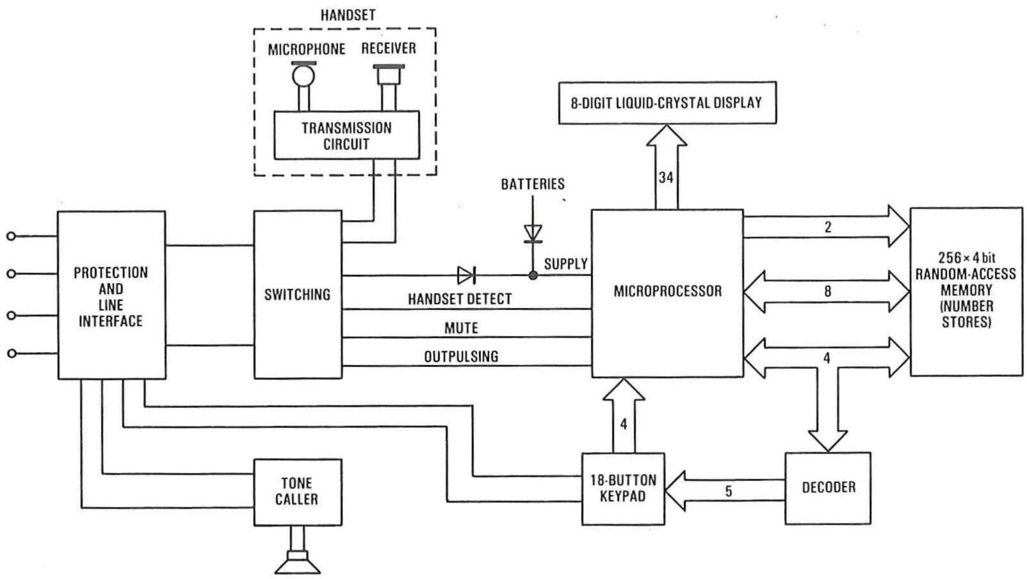


FIG. 10—Block diagram of Sceptre 100

and for a short time afterwards;

(*c*) the need for a power supply if 2 or more telephones with nickel-cadmium batteries were connected to the same exchange line.

Primary cells were therefore chosen to avoid the extra cost of meeting requirements (*b*) and (*c*). Manganese-alkaline cells were selected in preference to carbon-zinc or lithium cells because they are easily available to the customer, are relatively leak resistant and have a fairly high capacity. The AA-sized cells used in Sceptre 100 give up to 2 years continuous operation, regardless of telephone use.

It was considered important, however, that the telephone should provide the user with basic telephony when the batteries were discharged, or absent. A constant-current circuit which bleeds current in parallel with the transmission circuit to power the logic circuits when the handset is lifted was designed. As no power is taken from the line when the telephone is in the ON-HOOK condition, the memory, last-number redial and clock facilities are then inoperative. A battery condition indicator to warn the user of the need to change batteries was considered valuable, and is provided on the left of the LCD.

The general interconnection scheme of the logic and other circuits is shown in Fig. 10, the microprocessor being central to all functions except the tone caller.

The logic circuit is contained on a double-sided through-hole-plated PWB measuring approximately 130 mm × 140 mm. It carries the logic components, gravity switch, actuator and carrier, LCD and keypad. Connections to the handset and line cords, battery and tone-caller transducer are made by 3 push-on connectors.

The Microprocessor

The microprocessor, or more strictly *microcomputer* as it contains a processing unit, program and data memory on the same IC, is an ITT Semiconductors SAA 6002 encapsulated in a 60-lead surface-mounting package. Of the total 60 leads, 34 are required to drive the LCD, and the remainder are used for data input/output, handset-lift detect, power, control lines and oscillator pins. The oscillator frequency used is 32 768 Hz (2^{15} Hz), derived from a watch crystal, which is trimmed during the manufacture of the telephone to be within ± 15 parts/million, a clock accuracy of 1 min in 6 weeks.

Keypad scanning is accomplished with the aid of a 4028 CMOS multiplex IC, which outputs a pulse to each row of keys in turn, a key depression being signalled by a corresponding pulse on a column input to the microprocessor. The 10-number-by-16-digit repertory store is held in the 5101S 256 × 4 bit random-access memory IC. The memory locations are cleared on power-up reset, preventing random information being recalled.

Outpulsing and control of transmission circuit muting is performed by 2 VMOS/vertical-DMOS† field-effect transistors, which are able to control the tens of milliamps of line current, while demanding negligible gate current. They are thus ideal for use with low-current circuits such as that used in Sceptre 100.

Protection against lightning surges is provided in 2 stages:

(*a*) by the gas-discharge tube (GDT) in the primary line jack; and

(*b*) by a voltage-dependent resistor close to the line terminals, which limits the telephone terminal voltage to 160–170 V if the transient is too small to fire the GDT, and during the short initial time before the GDT responds to a fast transient.

The Liquid-Crystal Display

The Sceptre 100 has an 8-digit 7-segment LCD. Two-way multiplexing is used (see Fig. 11) and this reduces the number of connections to $4n + 2 = 34$ (n is the number of digits) compared with $7n + 1 = 57$ required by a directly-driven display. The energising of wanted and unwanted segments is controlled by combinations of backplane and segment drive waveforms. Wanted segments are energised with full voltage levels and unwanted segments at half level. Because LCDs have a threshold characteristic, the wanted segments appear dark, whereas the unwanted segments appear clear.

The advantages of directly-driven displays are that they operate over a wider voltage and temperature range than multiplexed displays, but the Sceptre 100 display, with its well-regulated supply rail, will operate from −10°C to + 45°C, which is more than adequate. At low temperatures, however, the appearance and disappearance of segments on a changing display is rather slower than at room temperature.

† VMOS and vertical DMOS are structures used to enhance the current-carrying capabilities of field-effect transistors

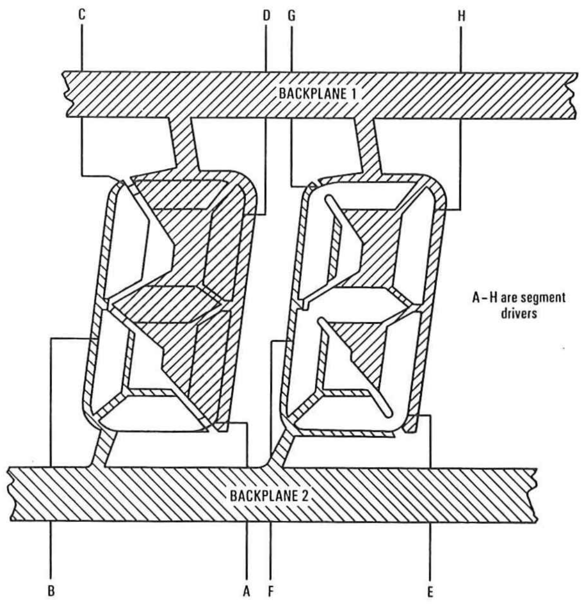
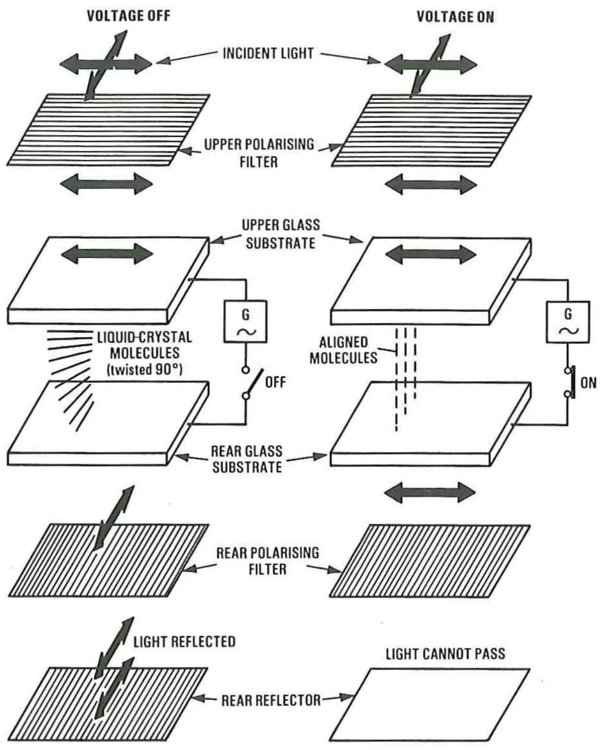


FIG. 11—Two-way multiplexed liquid-crystal display



(*a*) Unenergised segment (*b*) Energised segment (dark)

FIG. 12—Operation of liquid-crystal display

The mode of operation of an LCD is illustrated in Figs. 12(*a*) and 12(*b*). In the quiescent state, the plane of polarisation of light passing through the upper glass and polarising filter is caused to rotate by the thin layer of liquid crystal. It passes through the lower glass and polarising filter, which is at 90° to the upper polarising filter, and is reflected back along the same path. The display thus appears clear. In the presence of an electric field, the liquid-crystal molecules re-align themselves in the area between the transparent electrodes (active segments) so as not to rotate the light. The lower polarising filter then blocks the light under the active segments, causing them to appear dark or black on a clear background. (It is also possible to display clear segments on a black background by aligning the polarisers, instead of crossing them.) An AC drive waveform with negligible DC component is necessary to energise the segments in order to achieve a projected lifetime of over 10 years.

The Tone Caller

Incoming ringing current is full-wave rectified, smoothed and applied to the tone-caller IC, an AMI 2561, which is of the same type as that used on Viscount. A slightly different operating frequency is used, giving the 2 telephones distinctive sounds. The combination of frequencies used in Sceptre 100 is nominally 750/937 Hz, a ratio of 1:1·25 (a major third, musically), alternated at 23 Hz.

The output square waves, rich in harmonics, are applied directly to a high-impedance transducer, mounted in the base. A horn-like feature in the base acoustically loads the tone caller when the telephone is placed on a horizontal surface, giving an acceptable volume level with the relatively low-frequencies used.

CONCLUSION

The Sceptre 100 programme has proved the practicability and economics of using microprocessors in telephones. By comparison with its closest rival, the X-press callmaker, Sceptre 100 offers extra facilities with half of the size, half of the weight and at lower cost. The combination of in-house industrial, mechanical and electrical design with close contractor liaison, together with the use of modern technology, has permitted rapid translation of the conceived idea to a production instrument.

References

[1]WALKER, R. R. Viscount—A New Basic Telephone. *Br. Telecommun. Eng.*, Oct. 1982, **1**, p. 161.

[2]HANSEN, M. G., and DOCHERTY, B. G. Statesman—A Low-Cost Press-Button Telephone. *ibid.*, Jan. 1983, **1**, p. 211.

[3]ROWLANDS, C. E. The Electronic Telephone. *ibid.*, Oct. 1982, **1**, p. 148.

[4]RICHARDS, D. L. Telecommunications by Speech. Butterworth, p. 350.

[5]British Telecom Research Department, Internal Report No. 507.

[6]COLEMAN, A. E. Sidetone and its Effects on Customer Satisfaction. *Br. Telecommun. Eng.*, Apr. 1982, **1**, p. 10.

[7]WALKER, R. R., and MORGAN, A. J. The Electret: A Possible Replacement for the Carbon Microphone. *Post Off. Electr. Eng. J.*, Apr. 1979, **72**, p. 15.

Electronic Exchange System TXE4A

Part 2—Design and Operation

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UDC 621.395.345: 621.395.65

Part 1 of this article[1] described the general background that led to the development of TXE4A equipment. Part 2 describes the design and operation of this equipment, and provides an overall view of the maintenance philosophy embodied in the design.

INTRODUCTION

TXE4A electronic exchange equipments are cost reduced and technologically updated versions of the control area subsystems of the TXE4 RD electronic exchange system. The switching and peripheral areas remain unchanged. Confining the redesign work to the control areas of the system has enabled the desired cost reduction to be achieved without the basic system structure being changed. Also, new subsystems have been introduced to permit the full application of the new designs as extensions in TXE4 RD exchanges.

Previous articles on TXE4[2–4] described the overall system concepts that are common to both TXE4 RD and TXE4A; this article discusses only the redesigned subsystems which are identified in Fig. 1.

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TXE4A SUBSYSTEM DESCRIPTION

Cyclic Store

The cyclic store area performs 2 principal functions:

(*a*) monitoring the status of the line terminations by scanning on a periodic basis, and

(*b*) storing the semi-permanent exchange data relating to exchange terminations, and the data required for processing calls, such as code translating.

The output from the cyclic store is passed to the main control units (MCUs) for call processing.

The essential principles of operation of the cyclic store and of line scanning remain unchanged from the TXE4 RD, but the structure and realisation of the TXE4 equipment has been substantially altered. The number of terminations served by the TXE4 RD 12-rack cyclic-store tri-set has been

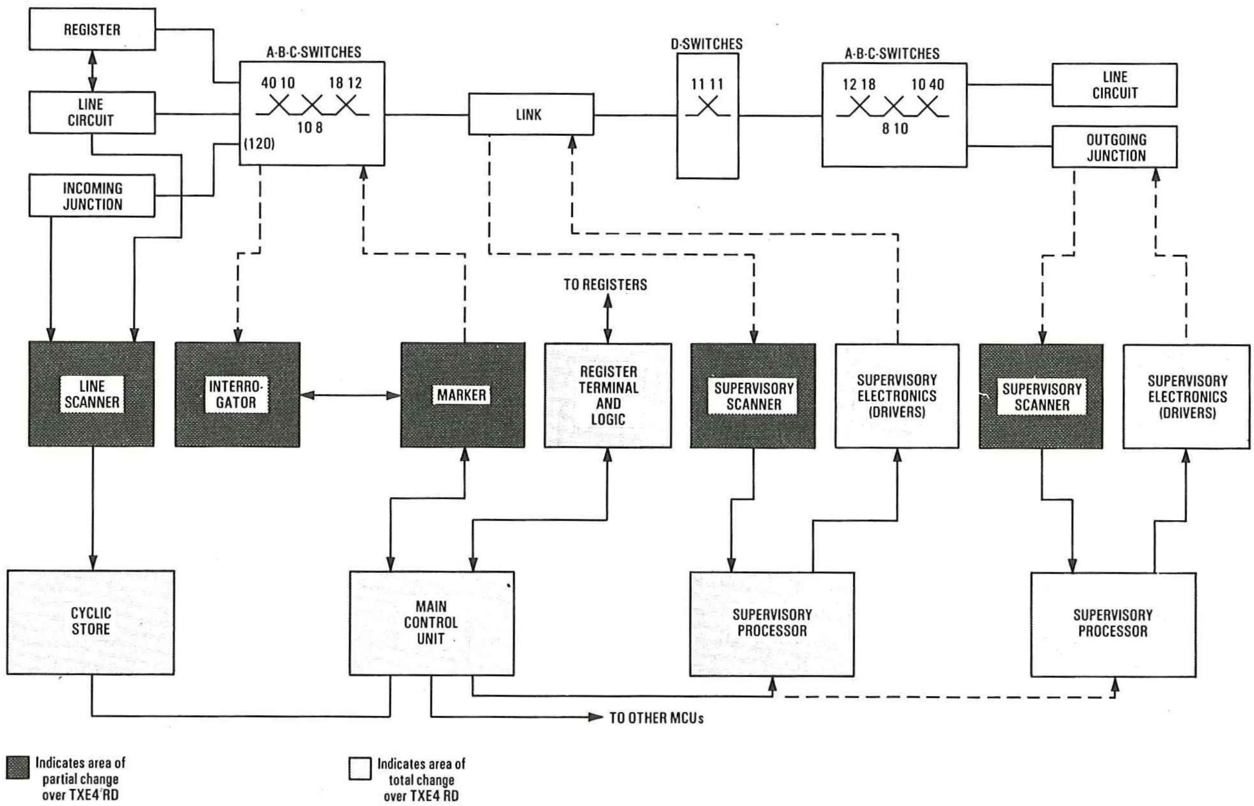


Fig. 1—TXE4A equipment

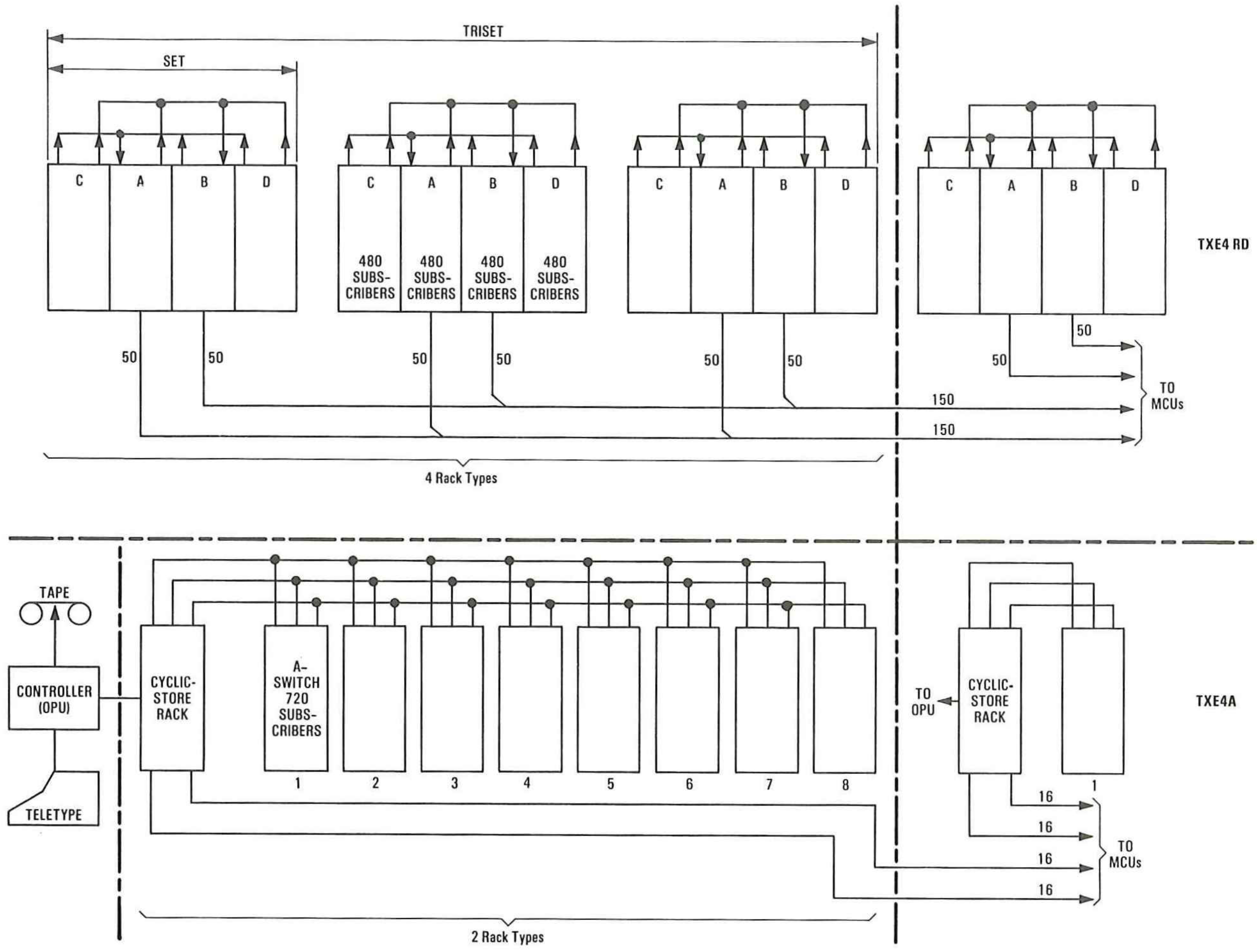


FIG. 2—Cyclic-store arrangements

used as the size of the basic building block for the TXE4A cyclic store. Thus each cyclic store module caters for 5760 subscribers, 1512 outgoing junctions (OGJs) and miscellaneous junctions, 1008 incoming junctions (ICJs) and 480 translations; up to 7 modules can be provided per exchange to give a maximum capacity of 40 000 lines. Fig. 2 shows the cyclic store arrangement for TXE4 RD and TXE4A.

The TXE4A cyclic-store module is made up of 2 basic rack types: a cyclic-store rack and a subscribers A-switch rack.

One cyclic-store rack and up to 8 subscribers A-switch racks are provided per module. Each subscriber's A-switch rack contains the line circuits, A-switches and line-scanning equipment associated with 720 subscribers' terminations. The cyclic-store rack contains the cyclic data store, state-of-line (SOL) logic, and the junction scanning equipment.

Fig. 3 shows the overall structure of the TXE4A cyclic store module.

Scanning techniques use discrete pulse-plus-bias gates to interface line terminations, and transistor-transistor logic (TTL) scanning. For the subscribers' terminations, the scanning function is performed on the subscribers A-switch rack and the resultant output is passed via triplicated balanced highways to the subscriber's SOL logic on the cyclic-store rack.

The condition or status of a subscriber's line is stored in the subscriber's SOL logic (triplicated for security) as a digit value and comprises 4 binary bits plus a parity bit, and is updated on every scan.

The exchange data is stored in a duplicated main data file and consists of 3 recirculatory metal-oxide semiconductor (MOS) shift registers serving the 12 ms, 36 ms and 156 ms scan. (The MOS shift-register function replaces the threaded-wire data stores used in the TXE4 RD design.) Data is presented cyclically at the output port in the same sequence as in TXE4 RD equipment.

The use of the MOS shift register to store the exchange data necessitates the adoption of security measures that embrace both error correction and the ability to reload data from a secure non-volatile back-up store in the event of serious failure such as loss of power. A magnetic-tape machine is used as the back-up store and is controlled from the operations processing unit (OPU), which functions as a cyclic-store controller.

Simple error correction to overcome transient corruption in the main data file is performed within an individual data slot. Each data-file slot contains a 10-digit word in a 5× 10-bit array (see Fig. 4). The first 9 columns each contain a data digit consisting of 4 binary bits and one parity bit. The tenth column contains a parity bit for each of the 5 horizontal lines. Any single bit error can, therefore, be identified by the horizontal and vertical parity co-ordinates. Correction is by inversion of the identified bit.

More serious data corruptions are corrected from the duplicate file or by reloading from the back-up tape.

The output from each of the 3 recirculating shift registers within a data file is fed via an output shift register before it is passed to the MCUs along a 5-lane balanced highway. A slot of data, when it is passed to the MCUs, comprises 11 digits, with the first digit being the SOL. These digits are transferred serially at 1·5 MHz.

The adoption of serial transfer has resulted in a fivefold

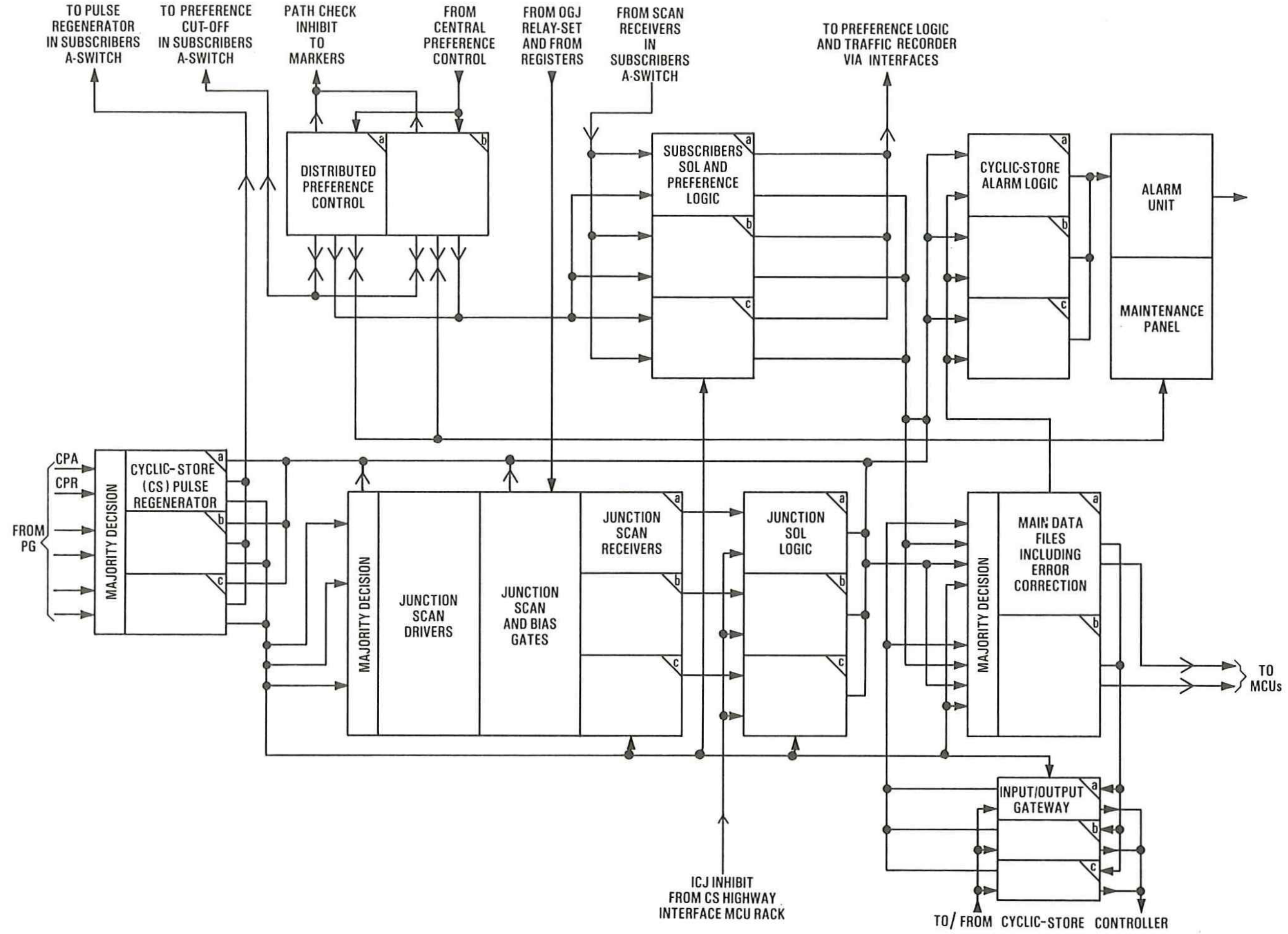
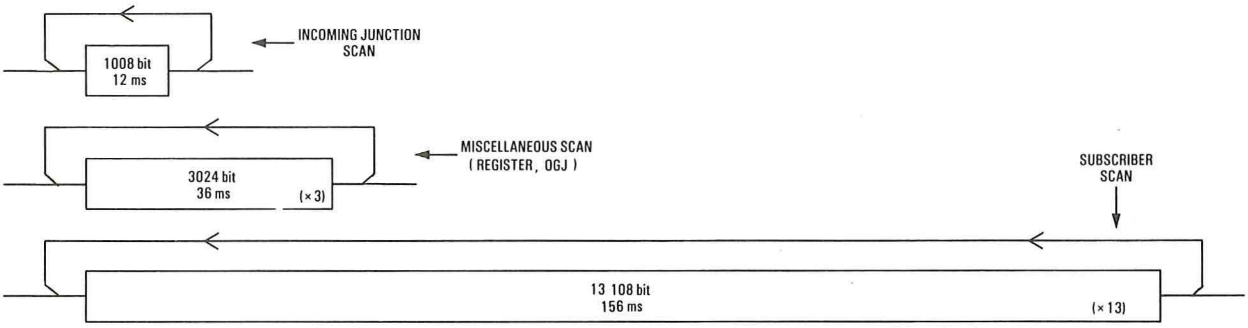
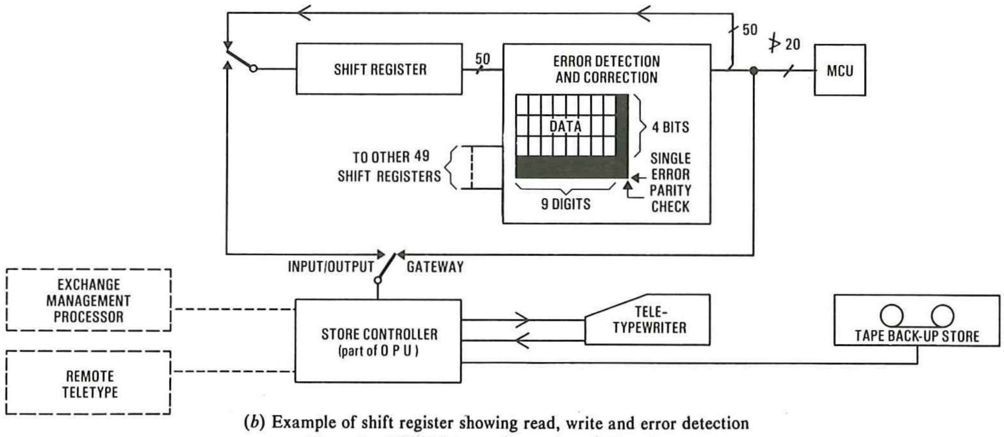


FIG. 3—TXE4A cyclic store



(*a*) Cyclic-store shift registers



(*b*) Example of shift register showing read, write and error detection

FIG. 4—TXE4A cyclic-store shift registers

reduction in the number of highways between the cyclic stores and MCUs compared with TXE4 RD, which employs parallel transfer.

Main Control Unit and Registers

Main control units (MCUs) are special purpose data processors using stored-program techniques, with erasable programmable read-only memories (EPROMs) for their main program stores. The most important function of the MCU is to accept new calls, connect one of its associated registers to the caller, interpret the digits received from the caller and arrange for routeing of the speech path through the switching network.

As with TXE4 RD, the number of registers provided in an exchange is determined by the type and quantity of traffic through that exchange. Each TXE4A MCU has a total capacity for 94 registers. The common design of register (based on the MOSTEK 3870 microprocessor) can deal with any incoming, outgoing, tandem (transit) or own-exchange call using 10 pulses/s. Multi-frequency (MF4) signalling is a standard facility of the system and can be added on a per register basis by the addition of a single slide-in unit per 2 registers. For security purposes, not fewer than 3 MCUs are provided per exchange. The maximum number of MCUs is 19.

Internally the MCU consists of 3 main areas (see Fig. 5) interconnected by 4 main data highways: DHA, which carries signals from the processing area; DHB, which carries signals to the processing area; EP, which carries the enable peripheral signals; and the YES/NO highway, which carries the test results from the peripherals.

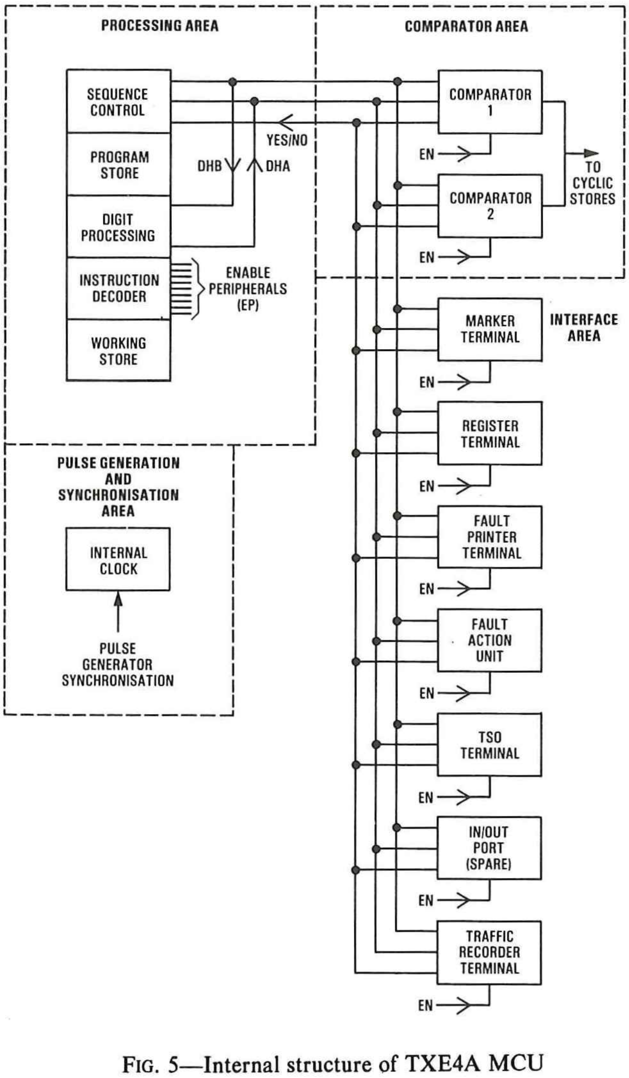


FIG. 5—Internal structure of TXE4A MCU

The processing area consists of 7 discrete sections: a sequence control, instruction decoder, working store, digit processing, program store, control panel and fault action unit. The sequence control logic selects the address of the next program step to be executed. The instruction decoder decodes program words held in the program store, deriving control signals for peripheral interfaces and other control functions. The working stores hold data relating to the call being processed, whilst the digit processing logic performs logic and simple arithmetic manipulation of digits from either the working store or the instruction decoder.

The control panel provides complete manual control of the program and gives visual indications of MCU operations. The fault action unit receives fault signals originated by the exchange hardware or detected by the MCU program causing the program to initiate a fault print-out.

The program store contains EPROM storage elements and associated control logic, the total storage capacity being 32 Kwords on 4 slide-in units (8 Kwords per unit). At the present time, approximately 12 Kwords are required to provide all the exchange connection facilities. The program is common to all exchange types, director or non-director.

Each program step takes 2 μs to execute, and only when information is to be transferred from the registers is this extended to 6 μs to allow for highway delays. The MCU is capable of carrying a program comprising 50 program modules; these are the executive program (module 00), variable store loading program (module 12) and 48 others, 24 of which are at present used. The executive program (module 00) is a constantly recirculating loop interrupted at intervals when it calls up any of the other modules (see Fig. 6). At the end of every module there is a return to executive instruction, except in one or two cases where one module leads directly into another. Each module seldom lasts more than 1 ms and, more usually, only a few hundred microseconds. Within the executive module, time is allocated to process each register in turn. The program is directed to register processing every 8·33 ms to process one third of the registers. Each register is processed every 25 ms and checked to see if it is dealing with a call; if so the register status is checked within its associated store. This gives information on what is to be expected from the register and the program responds accordingly. Fig. 7 shows the list of modules used and their functions; the executive program hooks the modules together in the order required for the particular call connection.

The grouping of programs into modules is a convenient means of grouping a much larger number of different programs, and most modules contain several independent programs. Entry value (EV) digits are used when a module is called up to specify which program, or which part of a program, is required within that module. Most modules contain subroutines which are short set-piece programs that can be used once or repetitively.

All programs keep a constant check on the validity of the data they are processing and, if any digit is found to be invalid, either an immediate print-out indicating the precise nature of the fault is generated or a dynamic stop is executed. In the latter case, processing stops and the program loops on the same step until the fault action unit intervenes to restart the program (2–3 ms) and generate a fault report. Only when this is completed is there a return to the executive program and normal operation resumed.

The working store is used as a temporary store to hold data relating to calls while they are being processed. Data is received from the digit processing logic via the DHA data highway and sent to the digit processing logic via the DHB data highway. The working store functional area contains

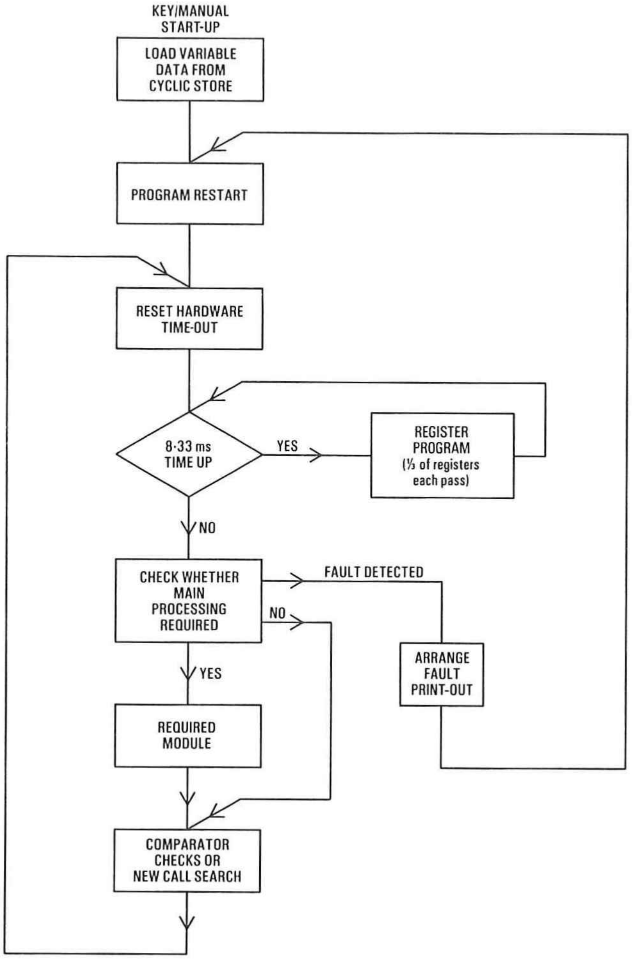


FIG. 6—TXE4A MCU program configuration

random-access memory (RAM) storage elements and associated control circuits. The storage capacity is 16 K 10-bit words, with an expansion capability to 32 K 10-bit words.

The store is split in 128 stores of 128 words, the first 2 being allocated for use within the main processing functions, a further 94 being allocated on a per register basis. Another set holds exchange dependent information loaded by module 12 or, on start up, from the cyclic store.

Module 00	Executive
Module 01	New-call analysis
Module 02	Prepare to connect register
Module 03	TSO and ICJ analysis
Module 04	CCB and paths 3/4 and 5/6
Module 05	Prepare outpulsing
Module 06	Terminating call
Module 07	Terminating call analysis
Module 08	Translation search analysis
Module 09	Outgoing processing
Module 10	PCC and post outgoing checks
Module 11	Fault print-out and program start checks
Module 12	Variable data transfer
Module 13	Path check
Module 14	Fault sequence
Module 15	Marker steering data
Module 16	Marker signalling
Module 18	Register satellite routiner
Module 19	Tone generator
Module 40	Register program input/output
Module 41	Register program phase 1 analysis
Module 42	Register program interdigit analysis
Module 43	Register program phase 2 analysis
Module 44	Register program outpulsing
Module 45	General subroutines
Module 46	Maintenance

FIG. 7—TXE4A MCU program modules

Registers

The registers are connected to the MCU via a register terminal. This terminal is responsible for transferring data to and from the MCU and its normal complement of up to 94 registers, which are housed in a register rack in 3 groups of up to 32 registers per group. There is a 10-lane balanced highway to the register rack and a 5-lane balanced highway from the register rack.

The registers are of common design for both local subscribers and ICJs although separate groups of registers are provided. They are based on the 3870 microprocessor, which contains a program to control such typical functions as:

(*a*) receiving customers' or junction signalling,
(*b*) detecting abnormal line potentials,
(*c*) providing dial tone,
(*d*) validating incoming digits and detecting IDP,
(*e*) checking, in conjunction with markers, path continuity within the switch network, and
(*f*) pulsing out to the distant exchange.

Two connections are provided from each register to the switch network. Both connections are on junction A-switches, one connection is primarily for the receipt of signalling, the other for pulsing out. Each register consists of a heavy unit containing termination control for 2 separate loop-disconnect registers and a planar card containing the microprocessor and electronic control logic. Where MF4 signalling is required, an extra plug-in unit (PIU) is provided (per 2 registers) on the same rack.

The information sent to the register terminal indicates the particular register concerned and the instructions to be sent to it. The register number is identified and the selected register addressed on a register number lead.

The MCU processes one register at a time by sending it a series of instructions; some are in the form of questions to which the register responds YES or NO; others are actions that the register should take.

So that the register can process independently of the MCU, up to 32 instructions can be sent to the register at one time and stored in a FIFO (first-in-first-out) memory. The microprocessor then deals with each instruction in turn.

THE OPERATIONS PROCESSING UNIT

The operations processing unit (OPU) is the man–machine interface with the system. It controls the transfer of data between the primary store (cyclic store) and the secondary store (magnetic tape). In addition, the OPU enables management functions to be performed and controls routining and testing of the exchange (see Fig. 8).

The OPU hardware consists of an MCU processor with interfaces to the cyclic store, local remote teleprinters, magnetic-tape transport, fault logic and the routiners.

The OPU software consists of a number of program modules, each specifically designed to suit the requirements of one of the functions. The program is controlled from an executive module, which is essentially a circulating program in which parameters are examined in a given order to determine which tasks shall be carried out. In general, all modules are entered from the executive module and return to it at the end of each pass.

The priority status for the various tasks are: fault print-out in progress, cyclic-store reload, magnetic tape update, searching routining, and reception of incoming teletype messages.

If data is corrupted within the cyclic store (primary store) and cannot be self corrected, the cyclic store alerts the OPU, which initiates a reload of that cyclic store from the magnetic tape. The time it takes to reload one cyclic store is less than one minute. Both levels of the cyclic store are loaded simultaneously.

The exchange data held on the magnetic tape appears in

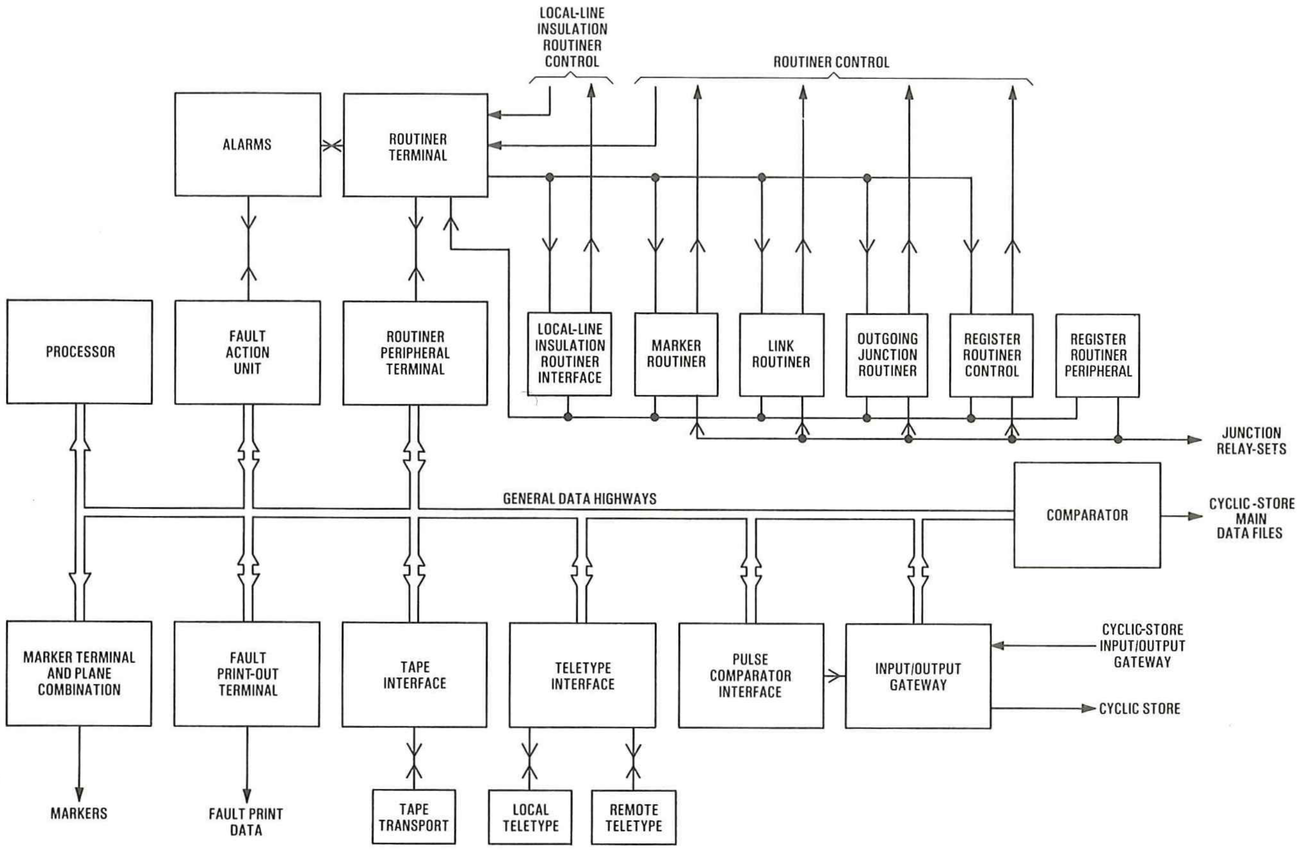


FIG. 8—TXE4A OPU functional subsystem

blocks of data, and each block appears 4 times. The data appears in 2 files and then twice within each file as a main and duplicate block. To identify the magnetic tape and to prevent a wrong or a blank tape being used on an exchange, each tape is given a volume header label peculiar to the exchange for which it is intended. A simplified diagram of the tape layout is shown in Fig. 9.

The tape layout enables any errors that occur on the magnetic tape caused by wear or damage to be overcome by the OPU. The OPU checks for parity errors and, if found, moves from the main block of data to the duplicate block and, if still incorrect, moves on to the corresponding block

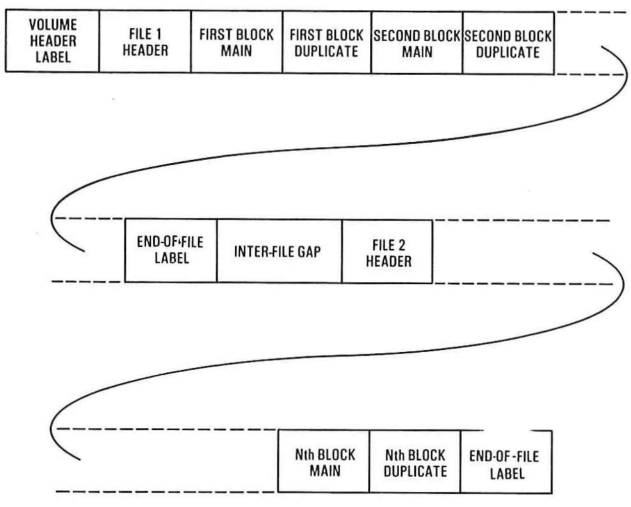


FIG. 9—TXE4A OPU program magnetic tape organisation

in File 2. If successful within the second file, the cyclic-store reload will continue within that file.

If further problems occur, the OPU returns to File 1 and moves between the 2 files as many times as necessary to complete a successful reload of the cyclic store. The number of re-attempts to read a block of data is printed out on the OPU teletype after the reload or the cyclic store, thus giving an indication that the magnetic tape is faulty or beginning to wear.

The OPU teletype enables staff to retrieve data from within the cyclic stores and, where necessary, to make changes and additions. For example, in TXE4 RD, the subscribers' exchange information is stored by a physical threading on the TXE4 RD cyclic store. In TXE4A, the cyclic-store data is inserted by using the OPU teletype. It is also possible to read blocks of data from the magnetic tape and print them on the OPU teletype.

Conversions from directory number (DN) to equipment number (EN) can also be made which, along with partial-contents searches, enable lists of data with similar characteristics to be displayed; for example, all coinbox lines or all MF4 telephones may be listed.

Lines can be made temporarily out of service (TOS) by simply typing TOS and up to 10 numbers at a time. The OPU changes the COS of that line to TOS and, where necessary, stores the original COS so that re-instatement at a later date can be as easily achieved.

Cyclic-store reloads and magnetic tape updates can also be initiated from the OPU teletype.

The routiners used in TXE4A are the same as those used in TXE4 RD. The control, however, has been transferred from the TXE4 RD MCU to the OPU. The OPU performs the same function as the TXE4 RD MCU, although the structure of the program has changed. The basic stages in each routining process is as follows.

The conditions for routining are set up on the routiner control panel on the miscellaneous exchange equipment rack (MEER) and the routiner is started manually from the control panel or automatically from the time switch. The panel call is made to the OPU via a calling gate specific to that routiner in the SOL logic.

The OPU accepts the call and transfers information from the routiner control panel. After further communication with the routiner, the OPU connects the required switching path to enable routining to proceed. Fault print-out (FPO) associated with the routining process is made to a teleprinter especially designated for routiner FPO.

CALL SUPERVISION

Each subscriber call is routed via a supervisory circuit such as a junction circuit or bridge link. These circuits facilitate monitoring of call progress, application of metering and final release. This process is achieved under the control of the supervisory processing unit (SPU).

In TXE4A, the SPU is not associated with the markers, but is an exchange subsystem in its own right. The design is based on the use of TTL circuits. Because one SPU may control all calls in the exchange, 3 identical security levels are used, which operate in synchronism and in parallel (see Fig. 10). During a call, it is necessary for the SPU to send instructions to each supervisory circuit. Distribution of these instructions is performed via equipment on the supervisory electronics racks (SERs). This equipment utilises TTL where practicable and is triplicated, in part, for security. The SER scans each supervisory circuit for information about the present state of each call; this information is passed to the SPU for processing. The SPU can process 6144 supervisory circuits and, therefore, exchange size rarely dictates the need for more than one SPU, although up to 3 can be provided. Each SPU is served by a maximum of 12 SERs. The number of SERs required is determined by the number of supervisory circuits in the exchange. This allows economy in provision, unlike its TXE4 RD counterpart, which is provided once per switching unit irrespective of the number of supervisories.

Each supervisory circuit has an EN or link identity. As new calls are set up through the switching network, an MCU sends this EN over highways to the markers together with other information about the call. The SPU monitors the MCU marker highways and detects new calls (see Fig. 11). The SPU has an array of EPROMs which are addressed

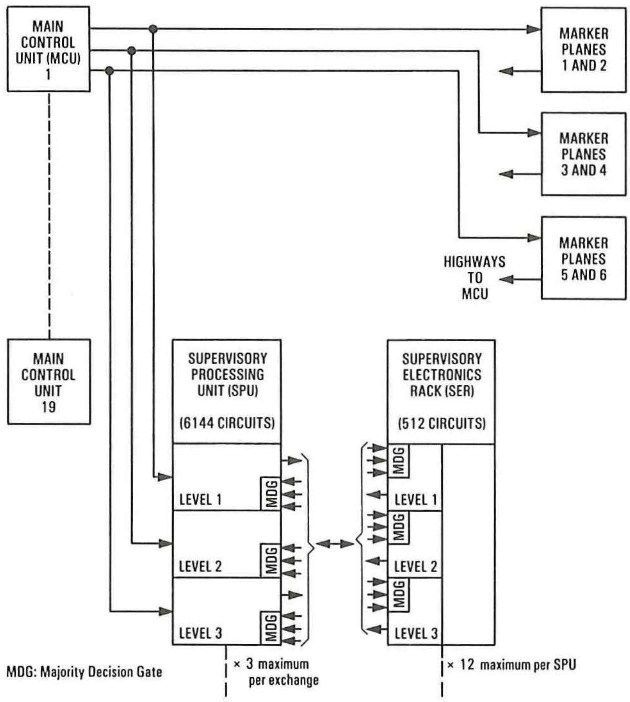


FIG. 10—TXE4A supervisory processing

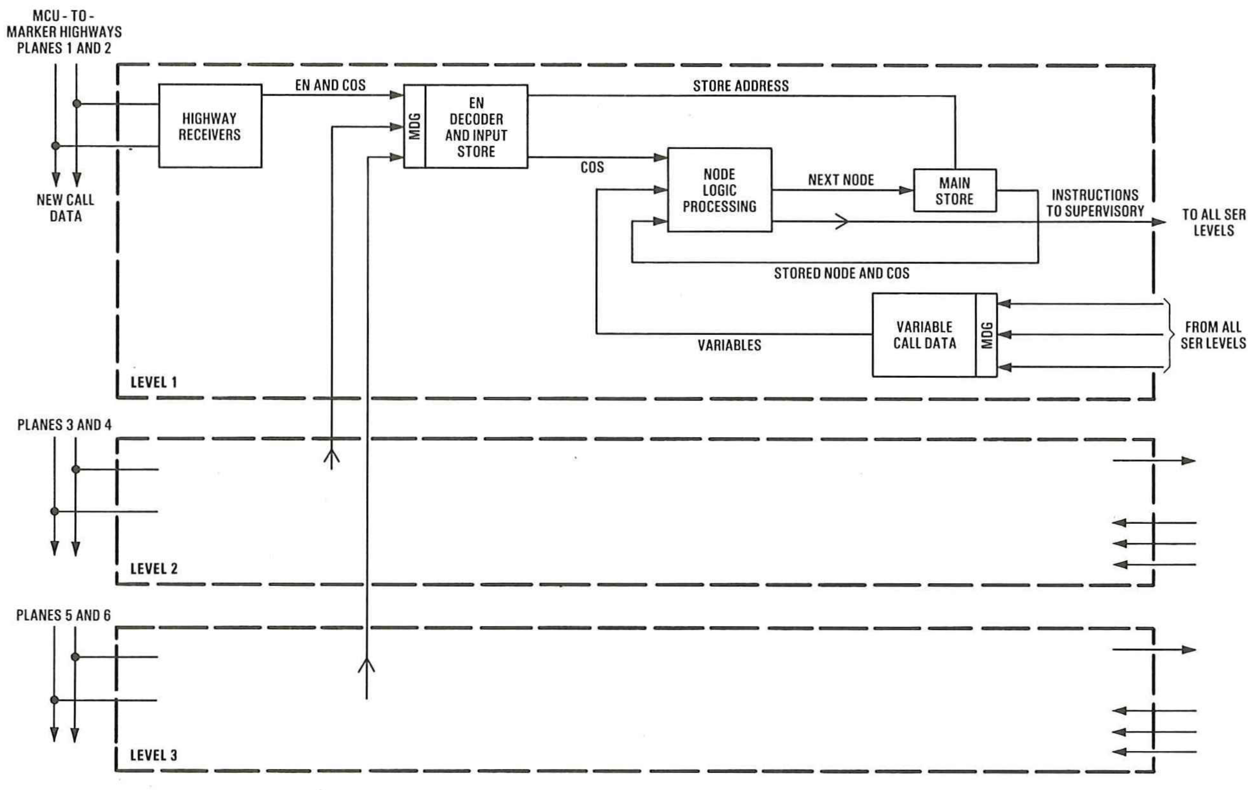


FIG. 11—TXE4A SPU structure

with the EN representing the main store address allocated to the supervisory circuit which is to be used. This address in the main store is loaded with the new call data required for subsequent processing of the call. The allocation of supervisory circuits to main store addresses varies according to the exchange dimensioning, which makes programming of these EPROMs exchange dependent.

The SPU has a 6 Kwords MOS RAM main store which can be equipped in 2 Kwords modules. This modularity allows economies in provision. The store can be utilised with far greater efficiency than the ferrite core store which is used in TXE4 RD. The main store contains data relevant to the processed state of each supervised call. One store address is allocated to each supervisory circuit. The stored data for each circuit is processed and updated cyclically once every 156 ms and a 12 μs time slot is allocated to each supervisory circuit. During each time slot, the main store data for one supervisory circuit, together with variable information related to that circuit, is applied to the node-logic module where a decision is made upon which instructions are to be sent to the supervisory circuit. The data to be returned to the main store is modified as necessary ready for processing during the next cycle. The node-logic program is stored on a number of EPROMs; this facilitates simple program modification if required. The node-logic program is contained within one PIU where 11 were required in TXE4 RD.

The TXE4A SPU is approximately half the size of a TXE4 RD SPU. It is more flexible and can process calls on up to 16 switching units. In a large exchange the TXE4A SPU, because of its processing capability, is one sixth of the size of the equivalent TXE4 RD SPU. The SER equipment, which embraces circuits that were dispersed over several rack types in TXE4 RD now occupies one fifth of the number of PIUs. Provision has been made for future enhancement of the processing capability of this subsystem.

CALL CONNECTION

Call connections are serially trunked through the switching network. Connection of the call path is achieved under the control of the marker and interrogator subsystem. The operation and design philosophy of the switching network and the marker/interrogator subsystems in TXE4A is essentially the same as that of TXE4 RD (which has been described in detail elsewhere); however, the essential features of interrogation and marking are as follows.

Interrogation

When a connection between 2 known terminations is required, it is necessary to find a suitable free path through the switching network. This function is known as the *interrogation sequence* and commences when an MCU sends over highways to the markers, the data which identifies the terminations to be connected. This data is EN of the termination. Each interrogator has access to crosspoints in its switching sub-unit to detect whether they are busy or free. Free paths are identified and sent to the marker for processing. A call path is always connected between an odd plane and adjacent even plane. The results of interrogation are processed by all odd-plane markers which deal with the switching units required. A suitable path is identified by each odd-plane marker and sent over highways to the relevant MCU, which choses one of the paths. The MCU relates its choice to the marker required, together with the class of service (COS) for the call.

Additionally, further information is returned over the highways to the markers towards the end of the interrogation sequence. This information, that is C-switch and path number, is required only by the TXE4A SPU. In the TXE4 RD design, the C-switch and path number is directly available to the SPU, since it forms part of the marker subsystem; this is not so in TXE4A where the SPU and marker are separate subsystems.

Marking

After the interrogation sequence, the odd and even markers serving the relevant switching sub units commence the path connection process. The markers have access to all switch crosspoints in their associated sub units and commence crosspoint operation for the chosen path from the link out towards the A-switches. Various checks are performed by the markers on the $+ve$, $-ve$ and p wires of the call path to ensure that a satisfactory connection has been achieved and that no faults have occurred. The checks required for each type of connection vary and will have been specified by a mode number sent from the MCU during the earlier interrogation sequence. The mode number is applied to an 8 Kword EPROM in the marker mode logic unit to determine which checks and other factors are relevant. The use of an EPROM not only results in significant space saving over TXE4 RD, but facilitates simple program modification if a design change becomes necessary. In TXE4A the range of path checks available is to be enhanced for improved fault detection.

To meet the aim of the cost reduction exercise, the control areas of the marker and interrogator have been designed to make maximum use of TTL. The circuits which interface the crosspoints and switching network remain essentially unchanged from that of the TXE4 RD design. The physical size of the TXE4A marker is half that of TXE4 RD so that a marker pair may now be accommodated on the BC switch rack. The size of the interrogator equipment has been reduced by about one third.

PULSE GENERATOR

System timing in TXE4A is based on the principle of a main pulse generator producing a small number of primary pulses for distribution and local regenerators, sited in the various systems, deriving further pulses to meet internal subsystem requirements. All regenerators are synchronised to the main pulse generator.

The pulse generator produces 5 timing pulses:

CPA—6 μs period, pulse width 2.67 μs
CPH—756 μs period, pulse width 2.67 μs
CPS—157 ms period, pulse width 2.67 μs
CPR—472 ms period, pulse width 2.67 μs
CPIW—6 μs period, pulse width 1 μs

The final pulse, CPIW, is only used in interworking situations and is required for synchronisation purposes.

The heart of the pulse generator is a 12 MHz crystal controlled, square-wave oscillator, the output of which is divided by 8 to produce a 1·5 MHz master timing signal. This signal is then used to drive a series of divider stages which provide the 5 main timing pulses (See Fig. 12).

Although the pulse generator is triplicated for security, only one level is assigned the task of supplying the master timing signal to drive the divider stages and distribution circuitry on all levels. If the master timing signal fails or drifts outside defined limits on the working level, then master timing is switched to another level.

The choice of working level for master timing is determined by cross enabling logic on the 3 levels. This is so arranged as to give a pre-determined order of working with a first choice, second choice and third choice. The pulses are distributed throughout the exchange on balanced highways and returned to the pulse generator for checking for loss and/or distortion of pulses.

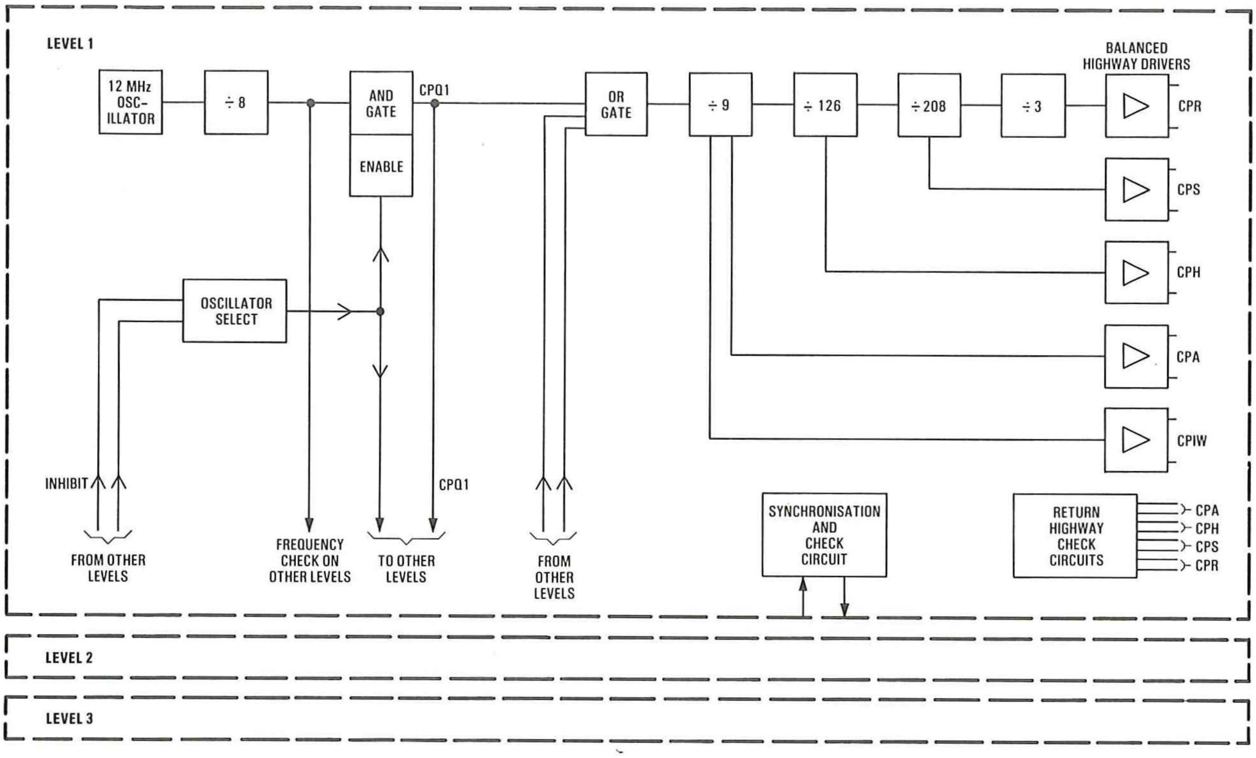


FIG. 12—TXE4A pulse generator

INTERWORKING AND INTERFACE EQUIPMENT

The design changes made to the TXE4A common control equipment have affected both the electrical signal levels and the coding structure to an extent that the new equipment is no longer compatible with the exisiting TXE4 RD equipment. Therefore, special interface equipment is required to cater for TXE4 RD exchanges extended with TXE4A equipment, and for new TXE4A exchanges, which still make use of the original design of switch blocks and peripheral equipment.

The basic differences between the 2 systems are shown in Table 1.

Interworking circuits are available to cater for the following situations:

(*a*) TXE4 RD cyclic-store data to TXE4A MCU,
(*b*) TXE4A MCU ICJ inhibit to TXE4 RD cyclic store,
(*c*) TXE4 RD odd-plane marker to TXE4A MCU,
(*d*) TXE4 RD even-plane marker to TXE4A odd-plane marker,
(*e*) TXE4A even-plane marker to TXE4 RD odd-plane marker,
(*f*) TXE4A MCU to TXE4 RD marker,
(*g*) TXE4A interrogator to/from TXE4 RD marker, and
(*h*) TXE4A pulse generator to TXE4 RD pulse generator.

In a TXE4 RD exchange extended with TXE4A equipment, a TXE4A pulse generator will be required to supply the corresponding clock pulses to the extension common control circuits. In order to maintain the existing TXE4 RD equipment in synchronism, the feedback path on each ring counter in the TXE4 RD pulse generator is broken and pulses from the TXE4A pulse generator are injected into the ring counters. The TXE4 RD pulse generator is thus driven directly from the TXE4A pulse generator.

Special interface circuits are also required on TXE4A to cater for the peripheral equipment which has been retained from TXE4 RD but which is now required to work to the new common control. Such interface circuits are used for fault print-out and traffic meters.

TABLE 1

Differences between TXE4 RD and TXE4A

	TXE4 RD	TXE4A
Signal levels	12 V	5 V
Logic	Negative	Positive
Coding	2 out of 5	Binary
Format	Parallel	Serial

MAINTENANCE PHILOSOPHY

The origin of fault investigation can come from any of the following sources:

(*a*) alarm indication,
(*b*) fault print-outs,
(*c*) automatic routines,
(*d*) manual routines, and
(*e*) fault reports from customers or distant exchanges etc.

The in-service experience at the first exchange (Leicester Belgrave[5]) using TXE4A equipment at present shows that 94% of all faults found are being indicated by alarms, print-outs or routines; only 6% comes from customers' reports or distant exchanges. This is encouraging as it shows that the second-attempt facility is being effective and that faults are being indicated and cleared before they can affect the customer.

To assist in fault detection, diagnostic manuals are available which, by starting from specific faults or alarms, can guide the maintenance staff, by reference to print-outs, measurements at test points, or the use of testers to the identity of the faulty PIU.

The repair philosophy of PIUs for TXE4A embraces a back-up centralised repair facility based on area repair centres (ARCs). Initially one ARC per region will deal with TXE4A equipment and will be provided with comprehensive programmable test equipment. In addition, the TXE4A

ARCs at London and Birmingham will be provided with the equipment necessary to program the PIUs containing EPROMs.

All TXE4 exchanges will be provided with spare PIUs. One spare PIU will be held on site for each of the unit codes used in the exchange except for junction and miscellaneous relay sets which are not considered critical. As a further safeguard until the ARCs are fully able to provide a quick turn-round time, buffer stocks will be provided at some ARCs in order to give adequate back up to the early exchanges until the population of TXE4A equipment and associated ARCs makes the need for the buffer stocks unnecessary. They will then be absorbed into the normal maintenance stock.

The faulting procedure is to trace down to a faulty PIU and then to change it for one of the spares which are held on site. The faulty PIUs can be repaired on site or, in the case of the more obscure faults, the PIU can be sent to the ARC for diagnosis and repair.

Depending on the expected repair time the ARC will either repair the unit and return it to the exchange or send a spare from its buffer stock. Thus, the exchange is left without a spare for the minimum period of time.

SUMMARY

The first installation of TXE4A exchange equipment at Leicester Belgrave has now been in service for 2 years. The service it is giving is good especially from the point of view of the low number of fault reports received from customers.There have been no major service failures or restrictions of service, and the in-built security and alarm systems are indicating faults which are being rectified before they can affect the customers.

Two further TXE4 exchanges using TXE4A equipment, Gipsy Hill and Clevedon, came into service during the second half of 1982. These exchanges are also providing a good service and confirms the early promise of Belgrave.

ACKNOWLEDGEMENTS

The authors extend their thanks to the various contributors who assisted in the preparation of this article.

References

[1] LEGGETT, G.R. Electronic Exchange System TXE4A. Part 1 — Background to the Development. *Br. Telecommun. Eng.*, Oct. 1982, **1**, p. 172.

[2] GOODMAN, J.V., and PHILLIPS, J.L. TXE4 Electronic Exchange System. Part 1 —Overall Description and General Operation. *Post Off. Electr. Eng. J.*, Jan. 1976, **68**, p.196.

[3] PHILLIPS, J.L., and ROWE, M.T. TXE4 Electronic Exchange System. Part 2 —Design of Switching and Control Equipment. *ibid.*, July 1976, **69**, p.68.

[4] HUGGINS, G., MILLS, W.B., and PATEL, C. TXE4 Electronic Exchange System. Part 3 — Security and Maintenance Features. *ibid.*, Apr. 1977, **70**, p.10.

[5] RITCHIE, D.A., and LAWRENCE, L.H. The First TXE4A Exchange. *ibid.*, July 1980, **74**, p.137.

Local-Line 8-Channel Carrier System for Caldey Island

M. PREECE†

Caldey Island lies off the South Wales coast just over 3 km from the coastal holiday resort of Tenby in the Swansea and South-West Wales Telephone Area.

Telephone service to the island is provided by an 8-pair subaqueous cable, which was laid in 1961 to replace an old radio link. Shared service was used up until 1971, and for the subsequent 10 years a 1+1 carrier system (WB900) was used to satisfy further demand until all spare capacity in the cable was exhausted.

In late-1981, a further 4 residents on the island applied for telephone service. Advice was sought from the British Telecom Wales and Marches Board Headquarters and British Telecom Headquarters on ways to meet these applications. Various possibilities were considered, such as an additional subaqueous cable or a radio link. Finally, it was decided to install a proprietary American carrier system capable of providing 8 speech channels on one unloaded pair.

The system, known as *RTEC CM8*, can accommodate high-calling-rate customers and consists of an exchange terminal mounted on the exchange miscellaneous apparatus rack and a remote terminal housed in a wall-mounted box, 400 mm high, 600 mm wide and 250 mm deep.

The exchange terminal is connected to the main distribution frame by 2 cables: one carries the 8 exchange lines; the other is a screened cable for the modulated carrier. The exchange terminal feeds power to the remote terminal over the unloaded pair.

†Swansea and South-West Wales Telephone Area

The maximum allowable attenuation between the exchange and the RTEC CM8 remote terminal is 7·5 dB at 1600 Hz. This can be extended to 14 dB and beyond by the use of one or more intermediate repeaters. As the nominal attenuation of the Caldey Island route was about 11 dB, one repeater was used.

The repeater is a sealed unit, 100 mm high,100 mm wide and 300 mm deep, which can be housed inside a cabinet shell (as in the Caldey Island project) or a joint box. Both the repeater and the remote terminal require an earth for protection purposes. The exchange unit includes its own protection

The system uses double-sideband amplitude modulation in the range 8–64 kHz from the customer to the exchange, and 88–144 kHz from the exchange to the customer.

The system has been operational since June 1982 and most users have commented favourably on the clarity of speech. As demand increases, other systems can be installed to give an ultimate capacity of 64 speech channels from the original 8-pair cable. In fact, a second pair will be used in the near future to meet increasing demand.

The author wishes to acknowledge the advice and assistance given by the British Telecom Wales and Marches Board Headquarters and the Transmission Department of British Telecom Inland Division during this project.

[*Editorial Note:* The editors have been asked to emphasise that there is no regional or national policy for the introduction of multi-channel local-line carrier systems.]

New Telecommunications Exhibition at the Science Museum—British Telecom's Involvement

D. C. WELLER†

UDC 621.39:061.4

This article describes BT's involvement in the preparation of a new telecommunications exhibition at the Science Museum, London, sponsored by Standard Telephones and Cables plc as part of its centenary celebrations.

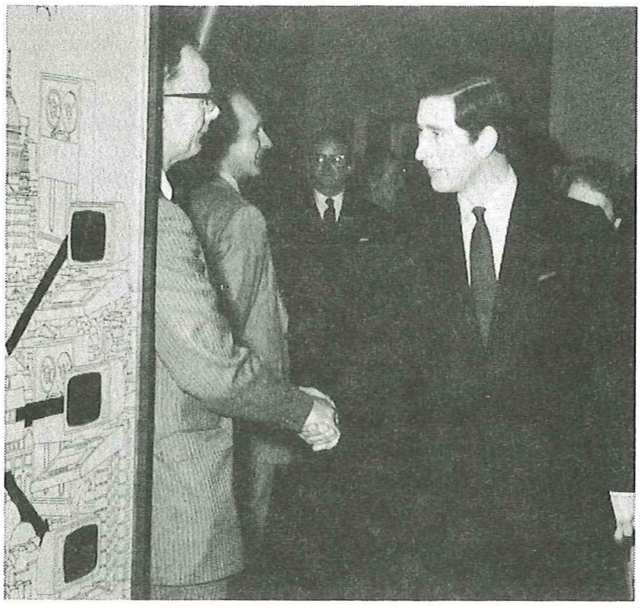
INTRODUCTION

A new exhibition at the Science Museum, London, entitled *Telecommunications—a Technology for Change*, was opened by His Royal Highness The Prince of Wales at a ceremony on 15 March 1983. This exhibition originated from a proposal by Standard Telephones and Cables plc (STC), which offered to give financial support to a telecommunications exhibition as part of its centenary celebrations. The objective of staging the exhibition is to present in easily understandable terms various aspects of telecommunications systems from the past, present and the foreseeable future.

British Telecom (BT) has provided substantial support to this exhibition and has been actively involved in planning and preparing the exhibits since the latter part of 1980. Similar assistance has been provided by STC, the sponsors of the exhibition. Contributions have also been made by other companies and organisations. The Science Museum has co-ordinated the activities and acted in an advisory capacity. Many items from the Museum's historical collections are included, and both its Audio-Visual and Electronic Display Unit and its workshops have devised new working exhibits for the occasion.

After one year, when the link with STC's centenary ceases, only minor alterations will be made, and the exhibition will continue as the Museum's permanent telecommunications gallery, with an anticipated life of some 5–7 years.

† Before his retirement, Mr. Weller was in the Exchange Systems Department, British Telecom Inland



His Royal Highness The Prince of Wales with the author at the opening ceremony
(Science Museum photograph, Crown copyright)

THE EXHIBITION

In reality there are 2 exhibitions. Part I is introduced by an audio-visual display to illustrate the impact on society of the ever-increasing ease, convenience and cheapness of worldwide telecommunications. This theme is followed by a relatively non-technical treatment of the general state of telecommunications at various periods. It is, in effect, a walk forward in time with random glimpses of the various aspects of telecommunications. The emphasis in this section is on set pieces; for example, a telegraph room in the 1850s, a ship's cabin of 1910, and the interior of a Lancaster bomber. The late-1920s have been selected for special treatment, and the period is featured as a small exhibition within the main exhibition; it was felt that this era heralded new advances in the field of telecommunications almost comparable with those of today.

Part II of the exhibition follows an exciting but more disciplined approach with technology presented in defined compartments. Radio, for example, spans from the Hertz and Marconi era to satellite communication; similar treatment is given to transmission, switching systems and terminals. These 4 branches of telecommunications merge into a finale in which a 20-min film entitled *Echoes* is shown. The film is designed to reinforce some of the concepts seen in the exhibition and to emphasise the importance of digital transmission.

BT's INVOLVEMENT

BT's contribution to this exhibition has been particularly important because of its considerable resource in both equipment and operational experience. Many departments provided assistance both in terms of technical advice and in the production of exhibits. Displays were specially designed and constructed to meet the specific needs of the exhibition. Considerable thought was required to establish the correct technological level for the exhibits, as it was necessary to appeal to non-technical visitors and, at the same time, permit the technically minded to appreciate the broader considerations. The advice and experience of the Museum's curators were invaluable in meeting these conflicting demands.

The following overview presents BT's contribution, firstly by outlining the exhibits that were readily available—standard items from past or current technology—and then by providing a more detailed description of the purpose-built functioning exhibits. Telecom Technology Showcase, BT's exhibition centre in Queen Victoria Street, London, in the main, provided the historical link; it acted in an advisory capacity and supplied many of the photographs and documents supporting the exhibition. Several items were loaned, one being a concrete Kiosk No. 3 which was recovered recently from Lingfield Park Racecourse and

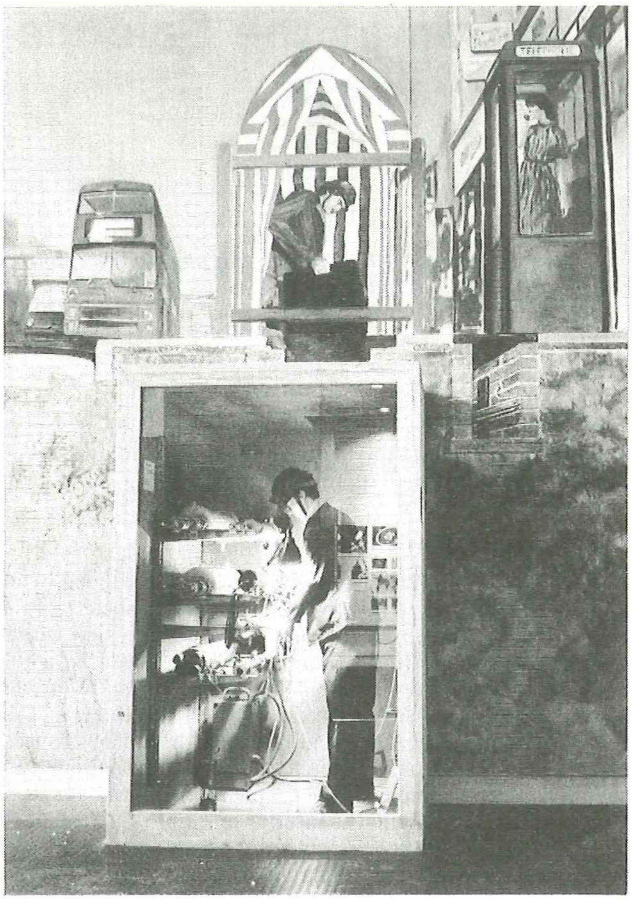
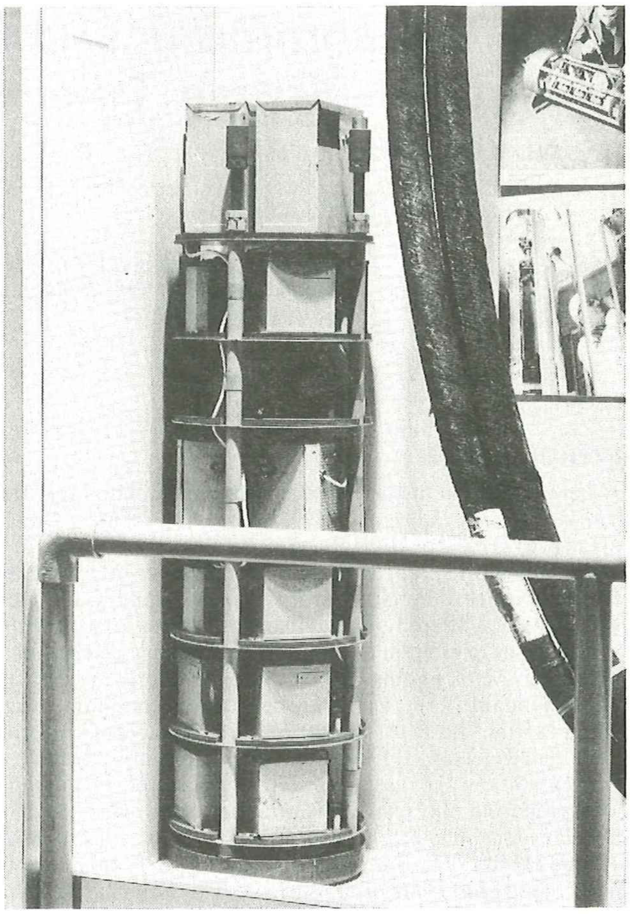


Exhibit depicting the inside of a manhole



Submarine-cable repeater and section of submarine cable

which will ultimately form part of Telecom Technology Showcase's own exhibition of historical kiosks.

An exhibit depicting a 'hole in the road' is given some prominence and the theme of the exhibit is to show that, even in this age of micro-electronics, the repair of underground cables is still an essential part of telecommunications. Samples of the Hitchin–Stevenage optical-fibre communications system and, as a further example of external plant, albeit pre-1900 vintage, an H pole complete with overhead linesman model and tools are exhibited.

The early design of submerged repeaters of the type used to link Holyhead with the Isle of Man and the 1956 TAT1 submarine cable repeater are included as representative of the pioneering days of this technology. Samples of deep-sea cables damaged by trawling and examples of cable trenching equipment reinforce the very important role played by BT's cable-ship fleet, and this is acknowledged by the fleet's flag, which is prominently displayed.

On display is part of the long-wave single-sideband telephony transmitter installed in the Rugby Radio Station in 1926 for the transatlantic service. Also shown is a parametric amplifier of the type installed on Goonhilly Aerial No. 2, which was brought into full-time service in 1968 to track INTELSAT II. Audio-visual media are used to good effect, and BT Reprographic Services have produced 2 programmes, the most ambitious being a 9-projector audio-visual programme which has been referred to earlier as the introduction to Part I of the exhibition. The other contribution is an audio-visual programme, entitled *Taking the Plunge*, produced in conjunction with the Systems Evolution and Standards Department of BT Major Systems. This outlines the events and decisions leading to the development of System X.

BT Pictorial Services and Telecom Technology Showcase have together contributed some 150 pictures supporting the various themes in the exhibition.

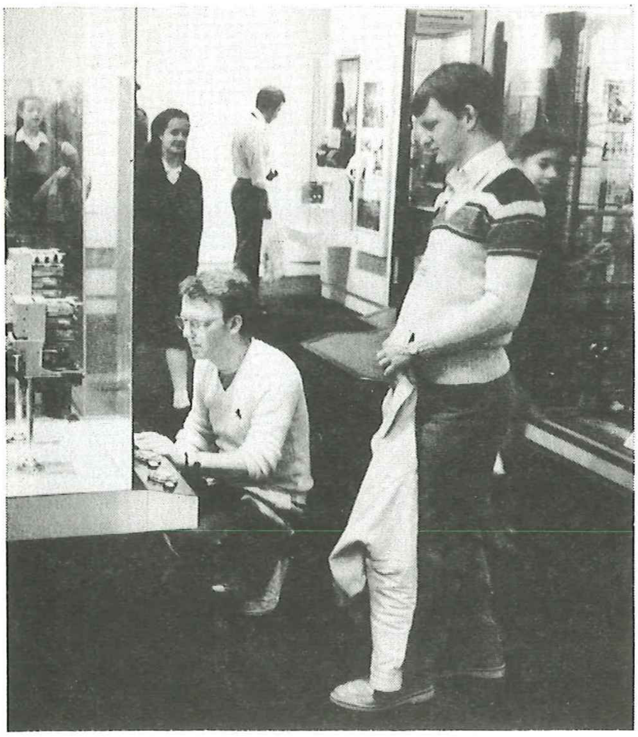
FUNCTIONING EXHIBITS

A number of functioning exhibits were designed and built in order to enable visitors to the exhibition to operate exhibits. The Circuit Laboratory of the Exchange Systems Department of BT Inland Division has been heavily committed to this work and produced the 6 exhibits described below.

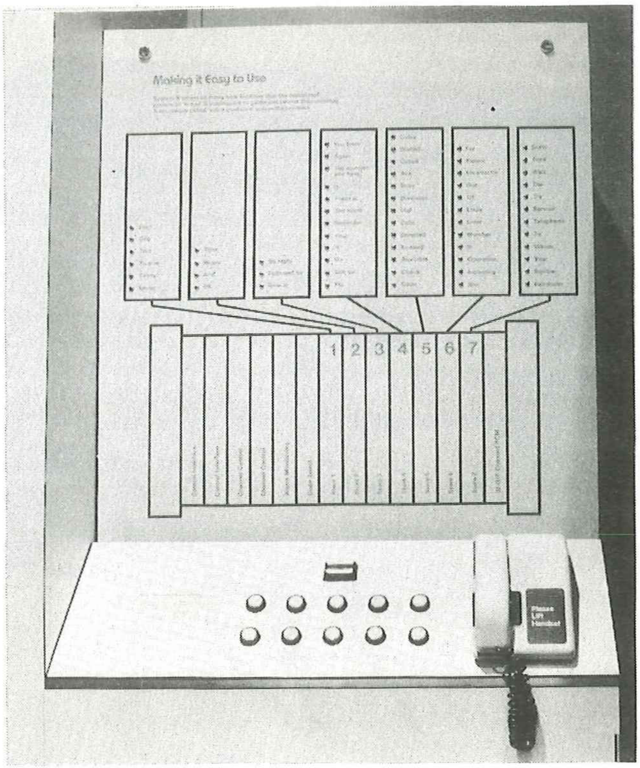
Strowger, although outdated, can still attract public interest, principally because things can be seen working. Two exhibits in Part I of the exhibition show Strowger equipment in operation. The first demonstrates group and final selectors stepping under dial control. The visitor selects either a normal 10 pulses/s dial or a special dial to permit observation of the selector mechanism when it is stepping slowly at 2 pulses/s. To convey the complexities of a telephone exchange the second exhibit comprises 3 fully-equipped racks of Strowger equipment interconnected to provide a 4-digit non-director numbering scheme. Ten telephones are also provided and visitors can set up calls, observe progress through the switching stages, and hold conversations.

The principles of Packet SwitchStream (PSS) are demonstrated by means of an audio-visual panel display. Three simulated PSS exchanges handle input data from associated terminals. The transmission and storage of data is represented by travelling or static alphanumeric displays, and the concept of packaging data is demonstrated by transmitting interleaved words/phrases either direct or via alternative routeing. The visitor is offered a menu of questions about PSS, and by operating press buttons the answers are displayed.

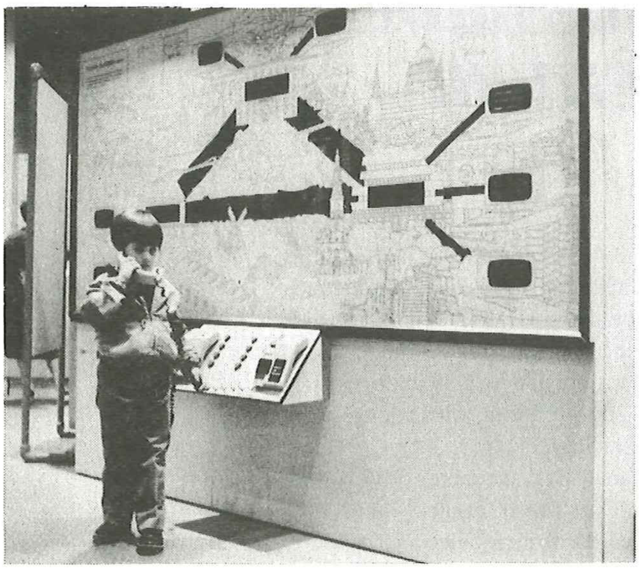
A simulated voice-guidance display permits the visitor to listen to a selection of System X messages, and to see how



Visitors viewing the Strowger-selector display



System X voice-guidance display



Packet SwitchStream display

the message was constructed from individual words. An engraved screen displays all the words used in the selected messages and, as the chosen message is heard, the appropriate word is illuminated.

Computer colour graphics with audio commentary are used to convey the basic principles of pulse-code modulation. The importance of an adequate sampling rate, quantisation and digital encoding for transmission are covered, and the presentation concludes by showing how more than one data stream can be sent over a single transmission path.

As a supplement to the historic overview of System X referred to earlier, a colour graphics display to convey in simplified form the principles of time-space-time switching was produced. An audio commentary guides the visitor through the visual-display presentation and then invites the visitor to become the 'central processor' and route connections through the system by allocating the appropriate cross-points and time slots.

A solid-state short-announcement repeater to demonstrate digitally-stored speech was produced by the Switching Control and Software Division of Systems Evolution and Standards Department, BT Major Systems. The visitor is invited to listen to a 16 s continuously-repeating announcement that was recorded and stored in 16 electrically-programmable read-only memories.

CONCLUSION

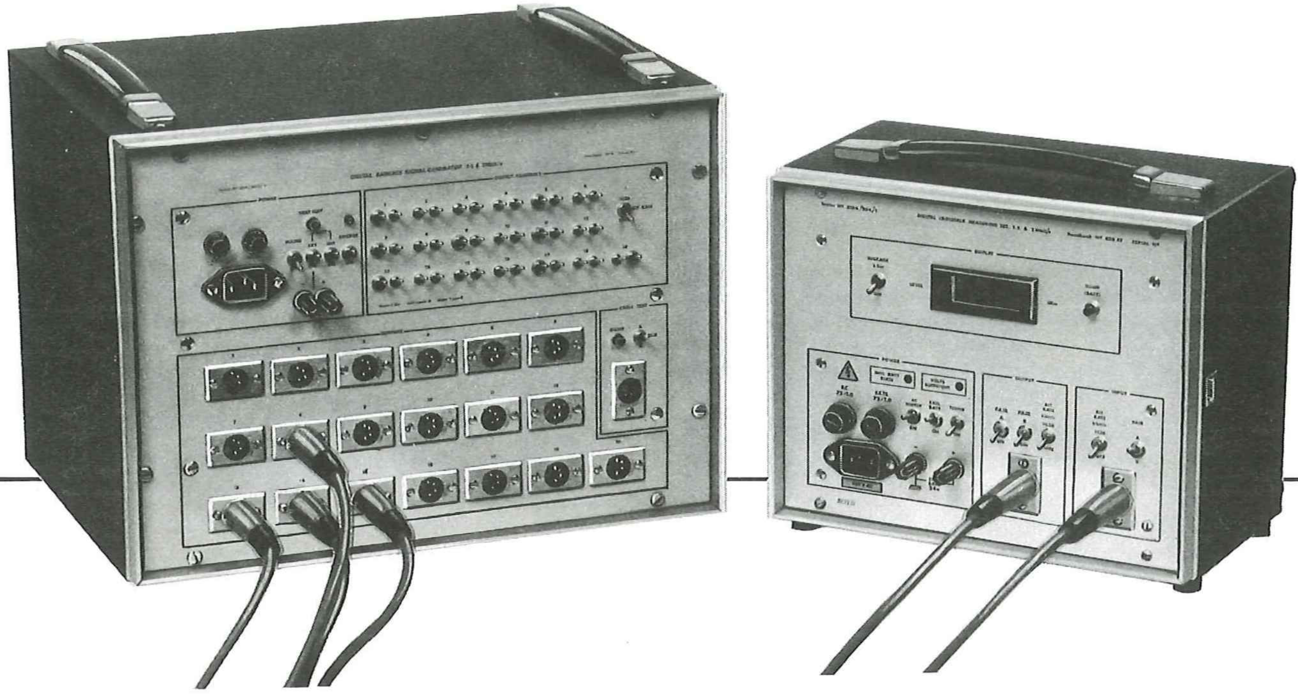
It is hoped that BT's commitment to *Telecommunications—a Technology for Change* will be a source of interest and education to all who visit the exhibition and will continue the policy of developing public awareness of past developments and interest in future trends.

ACKNOWLEDGEMENTS

The exhibition was made possible by the support and co-operation of many departments in BT. These include the Marine Services Division, British Telecom International (BTI); Norwich Telephone Area Museum; London South Central Telephone Area; Inland Customer Services Department, BT Inland Division; Technology Executive Personnel Division and System X Development Department, BT Major Systems; and Personnel Services Department, BT Headquarters.

Thanks are extended to Mr. D. J. Wither, Chief Engineer, BTI, for his assistance; to Ms. L. M. Holland, Mr. J. Tuppen and Mr. S. T. Dean for their advice on the preparation of Circuit Laboratory exhibits; and to the staff of the Circuit Laboratory who produced the exhibits.

Thanks are also extended to Messrs. W. K. E. Geddes, E. C. Davies, A. L. Rowles, D. D. Swade, P. J. Turvey, and I. M. Ball of the Science Museum for their assistance and advice. Their contribution to the success of this exhibition cannot be overstated and is a further example of the long and continuing tradition of the close relationship that exists between the Science Museum and BT.



Digital Testing of Metallic-Pair Cables

I. G. DUFOUR, C.ENG., M.I.E.R.E.†

UDC 621.395.3:621.374:621.315.213.12

This article describes digital test equipment used to evaluate the 2 Mbit/s digital performance of existing metallic-pair junction cables originally installed for audio transmission. Two types of tester, barrage testers and a digital crosstalk analyser are described. These have different but complementary applications. This article is based on a paper[1] presented at the International Wire and Cable Symposium, Cherry Hill, USA, October 1982.

INTRODUCTION

In the UK, the need to convert circuits in the junction network from analogue to digital transmission is increasing in line with the acceleration in the exchange modernisation programme. The use of optical-fibre cables[2] and purpose-designed transverse-screen cables[3] are obvious ways of providing digital transmission facilities, and these are amongst the options available to the planning engineer. However, there are still many instances where the utilisation of an existing audio cable is economically attractive.

The difficulties in predicting the 2 Mbit/s digital performance of cables originally installed for audio use have already been detailed in an earlier article[4]. This article deals with the types of tests needed on cables and the test equipment being used in the field.

For digital transmission systems, in order to have a low system error rate it is necessary to have an adequate signal-to-noise (S/N) ratio at the regenerator input. The S/N ratio is dependent both on the regenerator section length and the cumulative noise from all sources, referred to as *barrage noise*. The principal sources of noise arise via near-end crosstalk (NEXT) and far-end crosstalk (FEXT) paths from other digital signals in the cable. Sources of crosstalk from other digital signals also arise from particular jointing, tail-cable and regenerator housing arrangements and via audio pairs as an intermediate stage in the crosstalk paths. All these latter effects are, for convenience, referred to as *third-circuit crosstalk* (3CXT).

PLANNING GUIDELINES AND THE NEED FOR TESTING

Given an existing audio cable and a need to provide digital transmission over it, the planning engineer needs to know how many systems the cable will ultimately support. One option is not to have any planning guidelines, but to test each cable individually to determine how many systems it will support. This can be very time consuming and also disruptive to existing circuits. Another option is to produce guidelines which indicate the number of systems that can be provided without failures. In this case there is no testing involved other than in determining the guidelines at the outset. However, worst-case conditions have to be assumed and, because of the wide spread of characteristics between individual cables, the guidelines would be excessively conservative for most cables.

In practice, a compromise between these 2 options has been adopted. Planning guidelines have been prepared that give regenerator spacing and system-fill data for a range of probabilities of failures. The data is derived from a statistical analysis of large numbers of measurements made on typical cables. The planning engineer uses the guidelines in the knowledge that in a small number of cases he will not achieve the required number of systems. Conversely, in many cases he will be able to provide more systems than the guidelines suggest. The actual number of systems that the cable will support is determined by pre-commissioning tests carried out after the interception of the pairs into regenerator housings. The guidelines cover the majority of typical cable types and sizes but, for circumstances outside the guidelines, extensive testing of an individual cable may be necessary. Extended tests are also needed where the pre-commissioning tests indicate difficulties.

TESTING REQUIREMENTS

From the foregoing the following requirements for testing have been identified:

(*a*) Tests to characterise cables and produce planning guidelines. Large amounts of crosstalk data are required so that the number of systems that can be installed on a cable can be predicted.

(*b*) Tests to confirm that the predicted capacity is actually achieved and to establish what extra capacity is available (pre-commissioning tests).

(*c*) Tests to investigate specific cables where the predicted capacity is not achieved.

(*d*) Tests on cables, prior to interception of pairs, where the planning guidelines indicate that the required system fill cannot be achieved, where the cable size or type is not covered by the guidelines, or where the guidelines indicate zero systems.

Of these, the second (pre-commissioning tests) is the most frequent field requirement. The test equipment to meet all the requirements is, therefore, based on 2 levels of testing. The first level, for the pre-commissioning test, uses a relatively simple barrage tester, which can be given a widespread distribution. The second level is a more complex tester, a digital crosstalk analyser (DCA), capable of making and analysing a variety of measurements, but with a more restricted distribution in the field.

BARRAGE TESTING

It has already been explained that the planning guidelines are based on intercepting more pairs than are required and that it is necessary to test the intercepted pairs to determine those which will actually support digital transmission. The fundamental requirement of a barrage tester is, therefore, to generate many pseudo-random transmit signals for connection to the transmit pairs and to measure the resultant crosstalk noise on each receive pair in turn.

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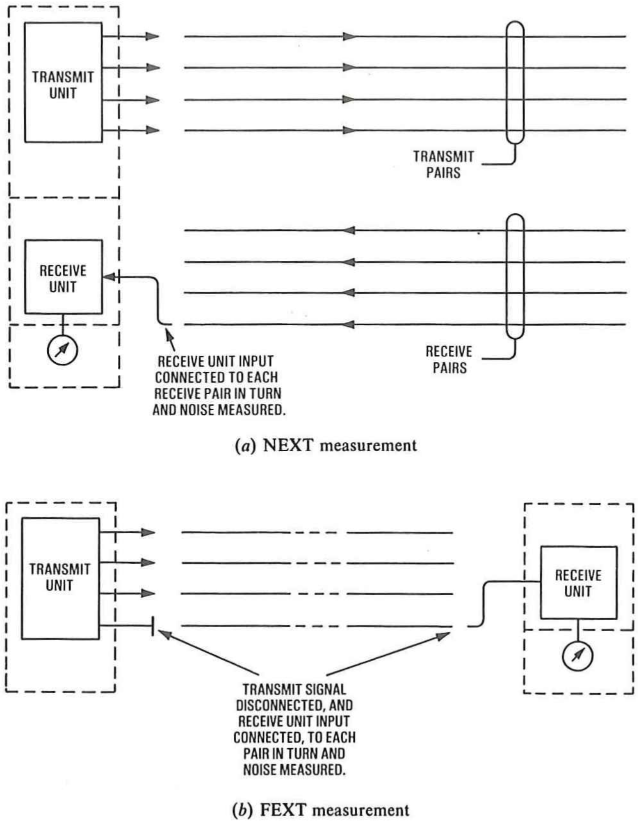


FIG. 1—Principles of barrage measurement

The principles of barrage measurements are shown in Fig. 1. From the planning guidelines it is generally known which cable configurations are limited by NEXT and which by FEXT. When NEXT is the main consideration, the tester is taken to each regenerator housing and tests are made first in one direction and then in the other. To test in one direction (see Fig. 1(*a*)), all the transmit pairs are connected to the transmit-signal outputs and each receive pair is connected in turn to the receive input of the tester. The measured readings are recorded. The maximum level of noise that allows a commissioning error rate of better than 1 in 10^{10} to be achieved has been established by laboratory measurement for a range of line insertion losses measured at 1 MHz. This information is in nomogram form and, for any known regenerator section line loss, the minimum acceptable noise level can be established. The measured readings are then compared to this to provide an instant GO/NO-GO result.

For FEXT measurements (see Fig. 1(*b*)), similar considerations apply except that the transmit signals are remote from the receiver. FEXT measurements can be time consuming because of the need to remove transmit signals from each pair in turn as they are measured at the other end. The DCA is therefore used in its BARRAGE mode, where the number of FEXT measurements to be made is substantial.

BARRAGE TESTERS

Three versions of barrage testers are already in use by British Telecom (BT) and a fourth version is just being introduced.

The first version was constructed using readily available parts: in particular, an existing 8-output 2 Mbit/s HDB3 (high-density bi-polar 3) pulse-generator, of which 2 are used for the transmit section. The unit is powered by a lead-acid battery (24 V). The main items needing construction were a receive amplifier incorporating a filter to simulate the frequency sensitivity characteristics of a regenerator, a

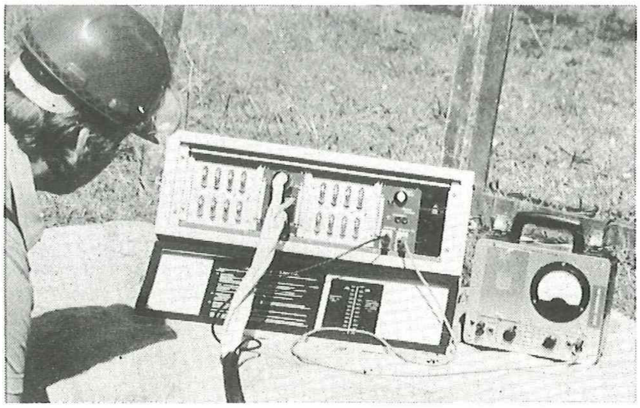


FIG. 2—Tester T63

case, and the test lead for making connections to the regenerator housing harness. The tester, known as the *Tester T63*, was first issued to field staff in 1980 and is shown in Fig. 2. It is used in conjunction with a standard 1 MHz level measuring set, also visible in the photograph.

The second version, similar in appearance, increased the number of outputs by using a new pulse generator with 18 outputs; two of these pulse generators employed in the design produce a 36-output tester. The new pulse generator also allows the upgrading of the earlier testers to 36 transmit signals.

A third version, called the *Tester T1019*, is also in use and is similar in concept to the second, but is produced by a manufacturer to his own design. It is in a modified construction practice and is shown in Fig. 3.

The fourth version (Fig. 4), now being introduced, has

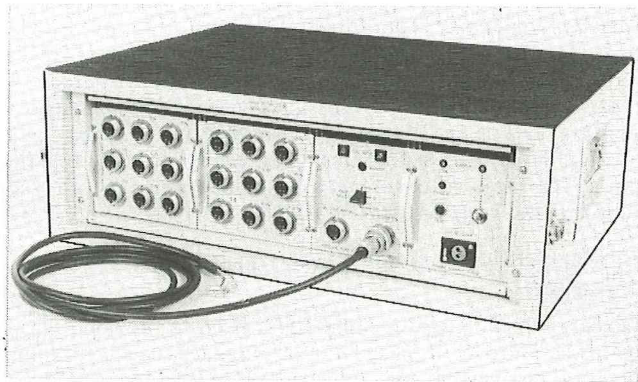


FIG. 3—Tester T1019

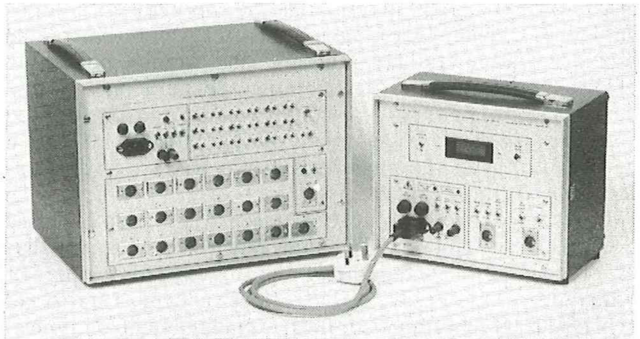


FIG. 4—Testers 309/310

several features not common to its predecessors that have been included as the result of very considerable field experience with the earlier versions; the main features are:

(*a*) The transmit and receive functions are in separate cases (called *Tester 309* and *Tester 310* respectively). This is more convenient for FEXT measurements. Where more than 36 transmit signals are required, 2 transmit units can be used.

(*b*) The transmit signals are selectable between all 1536 kbit/s or all 2048 kbit/s (HDB3 encoded). The 1536 kbit/s signals allow testing for the forthcoming 1·5 Mbaud 4B3T (4 Binary, 3 Ternary) line code using an appropriate nomogram.

(*c*) The transmit signals can be individually disabled. This allows limited optimisation of pair use without the DCA being used.

(*d*) The receive unit has an integral level measuring display (a liquid-crystal display showing the true RMS level of the incoming digital crosstalk noise).

(*e*) The receive unit includes 2 transmit generators to facilitate measurement of 3CXT in certain configurations.

(*f*) The units are of more robust construction than earlier versions.

(*g*) The units contain internal batteries. The current consumption of the signal generator (Tester 309A) is such that normal operation is from a separate heavy-duty lead-acid battery. However, the internal battery provides a few hours operation in the event of external battery failure and allows occasional use as a self-contained unit.

TESTERS TO CHARACTERISE CABLES AND FORMULATE PLANNING GUIDELINES

The original need for testers to characterise cables arose in the mid-1970s when it was foreseen that the large number of 2 Mbit/s systems required for network modernisation would cause problems on existing quad cables. It was anticipated that the planning guidelines, which had been satisfactory for lower circuit-requirement demands, would have to be revised. It was decided to base the new guidelines on the results of a substantial programme of cable measurements; but first a tester had to be designed for the purpose. The tester was named the *R92A Tester*[5] and is shown in Fig. 5.

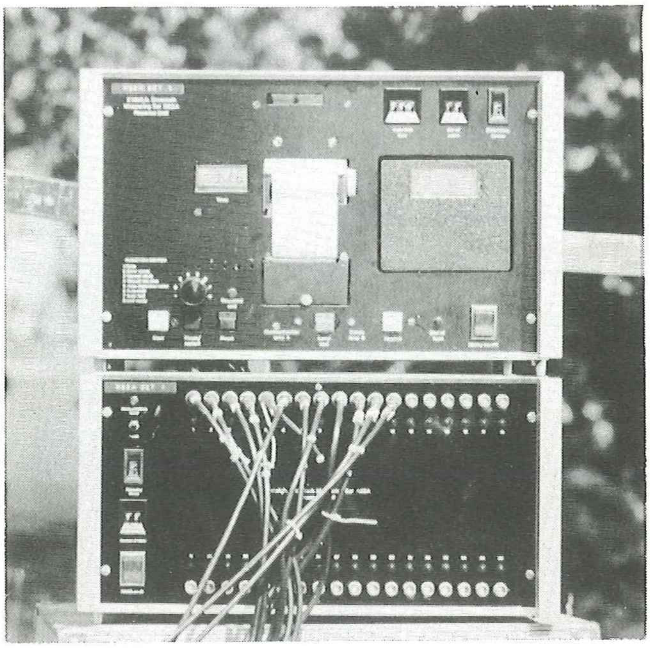


FIG. 5—R92A Tester

The signal generator and receive units of the R92A Tester are in separate cases. For NEXT (and 3CXT) measurements both units are used at the same site whereas, for FEXT and insertion-loss measurements, the units are sited at the opposite ends of a regenerator section. To assist in the control of the test sequences and to allow individual pair-to-pair and barrage measurements to be made, the switching of the transmit signals and of the receive unit is controlled by a microprocessor. A communication link is required between the 2 units and this can be a pair in the cable when units are at different sites.

NEXT (and 3CXT) measurements are carried out with both units at the same site. The measurements that can be made are:

(*a*) all pair-to-pair combinations using pseudo-random sequences,

(*b*) all pair-to-pair combinations using *all ones* signals,

(*c*) barrage measurements using pseudo-random sequences, plesiochronous,

(*d*) barrage measurements using pseudo-random sequences, synchronous,

(*e*) barrage measurements using *all ones* signals, plesiochronous, and

(*f*) barrage measurements using *all ones* signals, synchronous.

With the units at opposite ends of the regenerator section, FEXT measurements can be carried out in the same variations listed for NEXT. In addition, insertion-loss measurements and some other facilities can be included with minimum effort, such as error-rate monitoring and the amplitude distribution, sampled over a set period, of any extraneous noise on the cable.

The cable-pair test results are recorded on magnetic tape (cassette) for later printing and analysis, although a single-reading light-emitting diode (LED) display and a printer are provided for on-site inspection of a few readings.

The R92A Testers were first used in 1979 and have since completed an extensive measurement programme to characterise UK quad cables. The pair-to-pair measurements, in particular, have been used to formulate planning guidelines.

DIGITAL CROSSTALK ANALYSER

Experience with the R92A Tester indicated a need for cable evaluation and direct analysis in the field, the main applications in the UK being for trouble-shooting problem cables and evaluating the digital performance of cables where the planning guidelines show insufficient digital fill for the planners' needs. For other administrations, however, who have not yet characterised their cables, the ability to collect data to formulate planning guidelines would be a prime requirement.

Consideration was given to manufacturing more R92A Testers. However, although the R92A Tester had proved valuable, it has shortcomings.

(*a*) It is designed for use by specialists, not by normal cable test teams.

(*b*) There is little feedback to the user during tests.

(*c*) The results are not available on-site: obtaining print-outs from the cassette causes delay.

(*d*) There are insufficient digital output signals for measuring large cables or for assessing 3CXT effects.

(*e*) It is insufficiently rugged.

The DCA was therefore developed (jointly by BT and Racal) as an improved field tester based on the R92A. The main features are the use of 144 bi-directional signal ports and a desk-top computer controller to provide software control of functions and on-site computing power with operator feedback. The main measurement capability is as described earlier for the R92A Tester; namely NEXT, 3CXT and

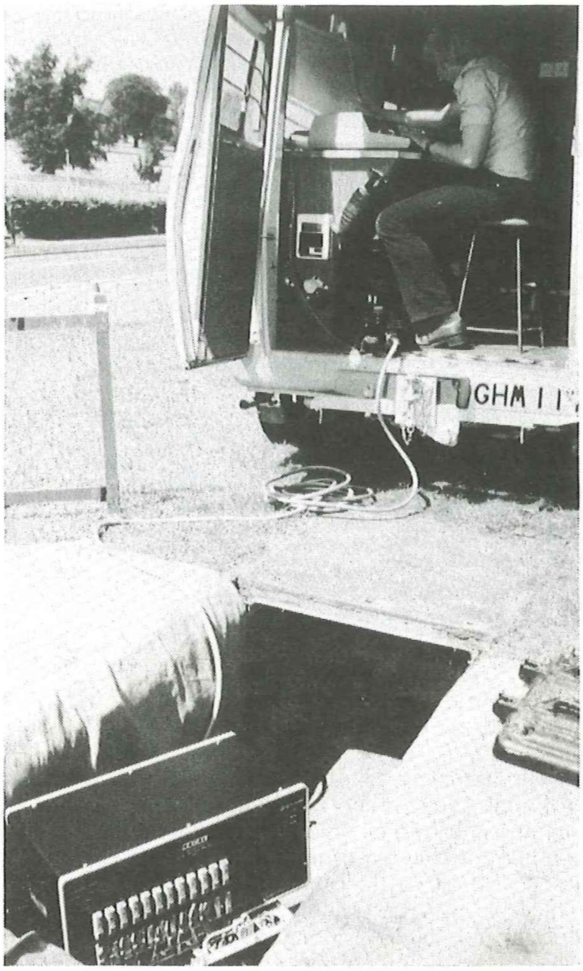


FIG. 6—Digital Crosstalk Analyser in use

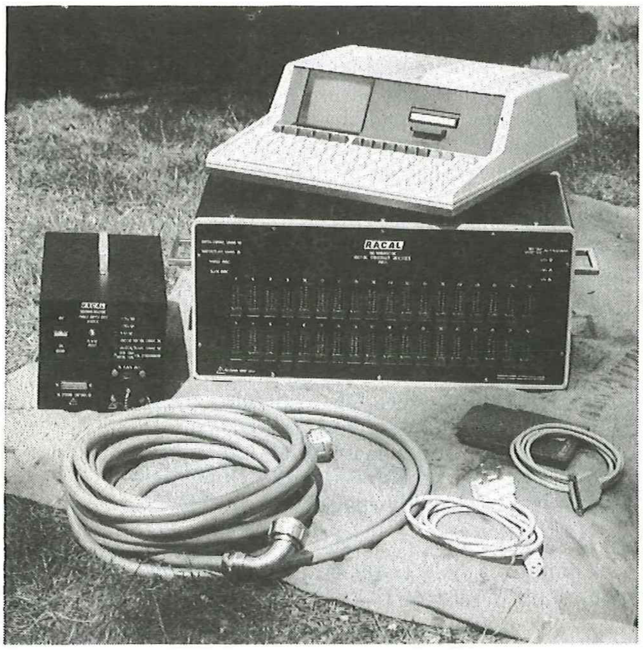
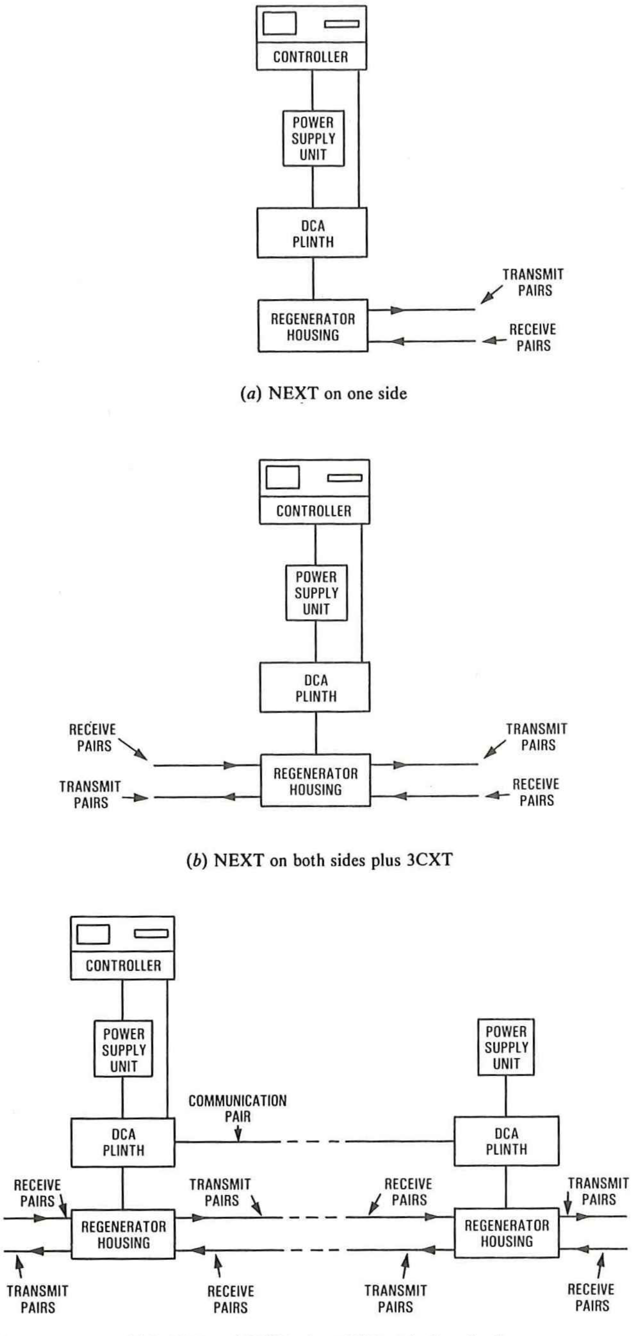


FIG. 7—Digital Crosstalk Analyser



(*a*) NEXT on one side

(*b*) NEXT on both sides plus 3CXT

(*c*) NEXT, and FEXT plus 3CXT, at both ends of a regenerator section

FIG. 8—Typical test configurations with the DCA

FEXT in pair-to-pair and barrage modes with pseudo-random and *all ones* signals. Also, for barrage testing, there is the option of using plesiochronous or synchronous signals. With the DCA, however, the opportunity was taken to include 2 clock frequencies so that measurements at 2048 kbit/s or 1536 (or, optionally, 1544) kbit/s could be made.

Prototypes of the DCA have already been used for field tests (Fig. 6) and production units are now being introduced. The equipment is shown in more detail in Fig. 7 from which it can be seen that the equipment comprises a DCA plinth unit, a power supply unit, the desk-top computer controller and various connecting cords. For UK use, BT has selected the Hewlett-Packard HP85 computer.

The software control of functions is very important as the test sequences and the analysis of the data can be varied to suit user requirements. For instance, the 144 signal ports

can be configured in any combination of TRANSMIT and RECEIVE. For UK use, 72 transmit outputs and 72 receive paths are normal. Similarly, the analysis programs can be adapted to suit any cable type and regenerator housing configuration. In the UK, the analysis is tailored to quad cables.

A single plinth unit is used for NEXT/3CXT measurements and 2 plinth units for FEXT and insertion-loss measurements. Any plinth can be used in LOCAL or REMOTE mode. Typical test arrangements are shown in Fig. 8.

Once assembled and connected to the regenerator housing (or cable pairs) the operator selects the appropriate tests. The software designed for UK application gives the option of a standard test routine or the selection of any particular type of test on any specific pair or group of pairs.

A key feature of the standard test routine is a print-out giving the optimum utilisation of pairs in a regenerator section to achieve maximum system fill.

The need to determine the optimum fill for a regenerator section can arise when a barrage test shows up a large number of failed receive pairs. In practice, the problem may actually be that one or two transmit pairs have a disproportionate effect. By using the DCA at this stage, the optimum combination of transmit and receive pairs can easily be determined.

For optimisation, the test equipment is set-up as in Fig. 8(*c*) and tests are first made in the BARRAGE mode from each end. Failed receive pairs are identified and all pair-to-pair measurements from the transmit pairs to them are read and stored. The readings are combined as power sums by the software and figures of merit are allocated to the pairs. The worst-transmit-pair data is then ignored and the calculations repeated to determine the number of usable pairs. The analysis continues until a diminishing return appears.

CONCLUSION

Although purpose-designed cables for digital transmission are increasingly important for a modern network, there is still a need to make use of existing audio cables. To maximise the use of such cables for digital transmission, BT has adopted a particular combination of planning guidelines and tests. A 2-tier testing hierarchy allows the use of low-cost relatively simple to use barrage testers for most applications with the more advanced DCA available to solve specific problems.

Barrage testers are used in other countries, but the latest UK version is in the forefront of design as it embodies the field experience gained from earlier versions. The DCA is a powerful tester for trouble-shooting problem cables, determining optimum system-fills and characterising cable performance: its features are not available commercially elsewhere.

ACKNOWLEDGEMENTS

The author would like to thank the many colleagues who have contributed to the introduction of the test equipment described. In particular, acknowledgement is made to Mr. R. J. Avery who carried out much of the design work on the first generation of barrage testers.

References

1 DUFOUR, I. G. Field Testers for Assessing 1·5 and 2·0 Mbit/s Digital Performance of Metallic-Pair Cables. International Wire and Cable Symposium, Cherry Hill, New Jersey, USA, Oct. 1982.

2 MARTIN-ROYLE, R. D., and BENNETT, G. H. Optical-Fibre Transmission Systems in the British Telecom Network: An Overview. *Br. Telecommun. J.*, Jan. 1983, **1**, p. 190.

3 DUFOUR, I. G. Transverse-Screen Cables. *ibid.*, Jan. 1983, **1**, p. 200.

4 DUFOUR, I. G. Provision of Digital Transmission in the Junction Network. *Post Off. Electr. Eng. J.*, July 1981, **74**, p. 92.

5 BORLEY, D. Digital Crosstalk Measurement. *Electronics and Power*, Sept. 1980, **26**(9), p. 737.

Book Review

Introducing Computerised Telephone Switchboards (PABXs). The National Computing Centre. John Wiley & Sons Ltd. 92pp. 15 ills. £6·50.

This book is a reprint of the main presentations given at a series of seminars arranged by the National Computing Centre and the Telecommunications Managers Association in the spring of 1982. At the time, the seminars were timely and interesting. However, both PABX technology and the political environment affecting telecommunications are changing rapidly; consequently, this book can be regarded only as a snapshot of the situation at the time when the papers were written. Even then, some of the detail was wrong, or already out of date. Over a year later, even though the situation has changed considerably, no attempt has been made to bring the text of the seminar papers up to date.

Because the original seminars were aimed at telecommunications managers, rather than individual users, the emphasis of the book is entirely on large PABX systems (that is, those with more than about 100 extensions). There is no mention of the increasing number of small stored-program control (SPC) systems already available or likely to appear soon; the title of the book is therefore rather misleading.

The anecdotal chapter on how British Leyland replaced a Strowger-type PABX 7 with a 248-extension SPC exchange during 1981 is interesting, but not very relevant to someone who is considering the acquisition of a new electronic PABX in 1983.

The final section of the book consists of tabulated data about various large PABXs. The status of the information is very mixed, some entries being out of date or misleading, while some are perhaps based on rather premature vendors' sales literature.

Some readers may find the brief summary of PABX facilities to be useful. Otherwise this is too ephemeral a text to be recommended.

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Project UNIVERSE—Local Area Networks and Satellite Communications

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UDC 681.3 : 621.396.946

This article discusses a high-speed digital communications system in which a satellite is used to link a number of local area networks which interconnect a variety of computer facilities. The advantages of satellite communications compared with terrestrial links are described, together with a historical survey of the use of the Orbital Test Satellite (OTS) for data experiments and the involvement of Marconi Communication Systems Ltd. (MCS) in those experiments. A description of Project UNIVERSE is given and the purpose of the project is described along with a more detailed description of the elements that make up the network such as satellite earth terminals, communication rings and terrestrial links. Future developments of such systems and their use as a means of business communication are considered, in particular, the factors affecting their growth, emphasis being placed on the specification and cost of equipment. This article first appeared in Communication & Broadcasting[1] and is reproduced here by permission of MCS.

INTRODUCTION

The existing terrestrial communications networks in developed countries have, until recently, relied upon frequency-division multiplex (FDM) trunk systems to fulfil their main communication needs. Since the late-1960s, administrations have been considering the introduction of digital transmission in their networks, using time-division multiplex (TDM) techniques. British Telecom (BT) made a policy decision in 1972 to use digital transmission in the network; since then, there has been a steady growth of digital equipment, starting with the use of 24-channel pulse-code modulation (PCM) systems and now extending into the local network with such equipment as that providing KiloStream and MegaStream[2] services.

The transmission of data within the public switched telephone network is at present restricted to 48 kbit/s services, for which leased lines must be used. This facility, although adequate for certain services, is already insufficient for the transmission of bulk data between business centres, be they banks, industrial concerns or research establishments. It will be some time before higher speed services are available nationally using terrestrial networks. The alternative to a terrestrial system is a satellite-based data system using small data terminals situated directly on customer premises; this has several unique advantages over a terrestrial system:

(*a*) the system is not distance dependent;
(*b*) point-to-multipoint communication is possible;
(*c*) the network can be expanded easily, or can be reconfigured;
(*d*) the quality of the link is often better than equivalent terrestrial systems, though the propagation delay can be a problem;
(*e*) high-speed links can be provided, depending only on the satellite design; and
(*f*) the service can be secure and independent of the common-carrier network if encrypted.

Practical realisations of such satellite systems are currently operational in the USA and will eventually be seen in Europe when the European Communication Satellite (ECS) and TELECOM 1 systems become fully operational.[3] These systems should provide new services additional to those available from terrestrial networks; great emphasis is being placed on the role satellite communications can play in the office of the future, with facilities for electronic mail, high-speed facsimile, video teleconferencing, etc.

The wide range of possible applications for the system has not yet been explored fully; Project UNIVERSE has therefore been set up, using the Orbital Test Satellite (OTS) as part of the distribution system. UNIVERSE is an experimental system using the OTS, the forerunner of the ECS.

PROJECT UNIVERSE

The UNIVersities Extended Ring and Satellite Experiment (UNIVERSE) is a project designed to investigate the facilities and protocols needed to provide digital business communications by linking together terrestrial and satellite networks, with particular emphasis on the use of communication rings for distribution within local area networks.

The project has participants from Rutherford and Appleton Laboratories, Cambridge, Loughborough and London Universities, GEC Marconi Research, Logica Ltd. and BT. It is funded by the Department of Industry, the Science and Engineering Research Council (SERC), BT, GEC Marconi and Logica, and is scheduled to last a period of 3 years.

The OTS System

Project UNIVERSE is the latest use of the OTS which, although now almost beyond its design life, is still being used for a number of experiments. The project can be seen as an extension of the OTS project; this was initiated by the European Space Agency (ESA), and was designed to evaluate satellite communication performance in the 11/14 GHz band as a forerunner of the ECS now being implemented in Europe.

Satellite business system experiments using the OTS were carried out between 1979 and 1981, involving 2 separate networks. The first experiment, called *STELLA*, linked Rutherford Laboratory (near Oxford), CERN (Geneva), DESY (Hamburg) and CNVCE (near Paris). The second experiment linked computers in ESA establishments in Italy, Germany, Holland and the Royal Aircraft Establishment (RAE) in UK, and was called *SPINE*.[4]

The experiments were carried out to evaluate link performance at 512 kbit/s and 1024 kbit/s data rates. These data rates were most suitable for transferring data between remote computers having large storage capacity; that is, greater than 300 Mbyte. Each computing centre shared the same satellite channel, using a time-division multiple access (TDMA) system, with a master station providing a timing reference for a data burst from each working station.

Marconi Communication Systems Ltd. (MCS) was

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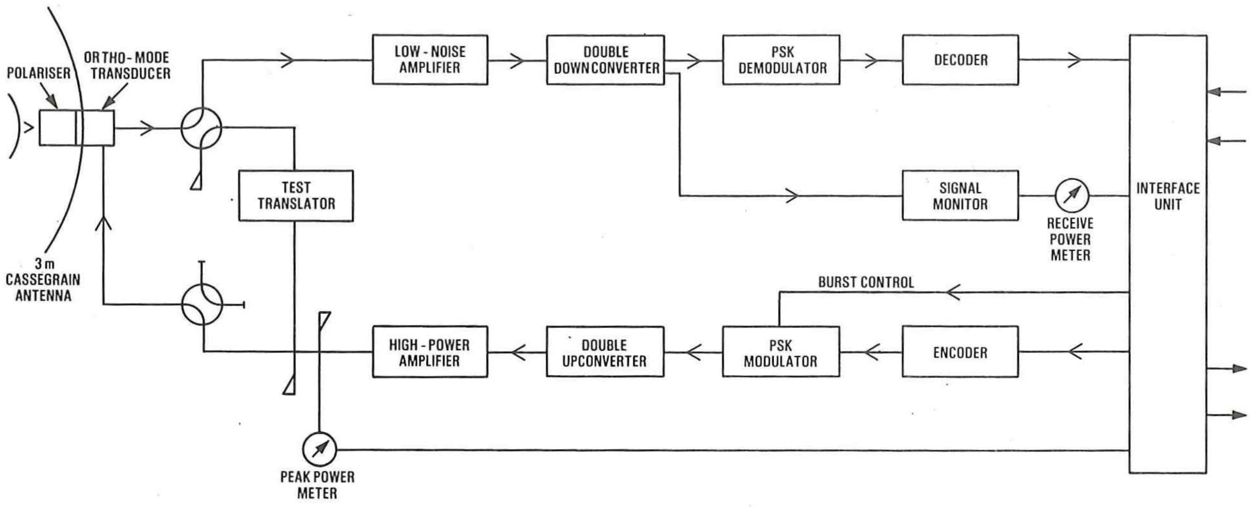

PSK: Phase-shift keying

FIG. 1—Block diagram of a data terminal for Project UNIVERSE

involved in both experiments, providing small data terminals at CERN, Rutherford Laboratory, RAE Farnborough and Darmstadt. In addition, MCS designed and built one of the main control stations for the 19 m diameter antenna at Goonhilly Downs, Cornwall[5].

Communication System

The communication system is made up of the following components:

(*a*) the satellite links (described later);

(*b*) the local distribution network at earth station sites in the form of digital communication rings;

(*c*) terrestrial links between University College, London (UCL), and Logica, capable of operating at megabit per second data rates;

(*d*) networks to CCITT† X25 Recommendation, using the BT public network Packet SwitchStream (PSS) service and SERCNET, which is the network operated by the SERC.

PROJECT UNIVERSE DATA TERMINALS

The data terminals for the Project UNIVERSE experiment are of MCS design, with MCS providing all of the terminals apart from the facility at the BT Research Laboratories, Martlesham. The data terminal, a block diagram of which is shown in Fig. 1, provides the means of transmission to, and reception from, the OTS. The terminal can be divided into 2 parts—the antenna and the equipment cabinet.

Antenna

The 3 m diameter antenna consists of 3 parts: parabolic reflector, feed and sub-dish. The parabolic reflector is of moulded glass fibre, the moulding process being of high precision to obtain the required surface contour accuracy. The reflecting surface is sprayed with a layer of aluminium. The feed system is a conical corrugated horn, followed by a polariser and orthogonal-mode transducer. The polariser characteristics can be varied to produce orthogonal linear or orthogonal circularly-polarised signals. The sub-dish, illuminated by the feed, forms a single unit with the feed assembly.

†CCITT—International Telegraph and Telephone Consultative Committee

The main dish is provided with a rigid support and can withstand wind speeds of up to 200 km/h; however, to achieve this, if the antenna is roof-mounted, it is likely that the roof will require reinforcement. The installation at the Marconi Research Laboratory is shown in Fig. 2.

The antenna is designed to work over the 11·45–11·8 GHz receive band and the 14·0–14·5 GHz transmit bands. The antenna receive gain is 49·2 dB and transmit gain is 50·8 dB. The figure of merit, (G/T), at 30° elevation is 22·5 dB/K, with the low-noise amplifier being mounted directly on the back of the dish. The transmitted equivalent isotropic radiated power (EIRP) is 71 dBW maximum.

With such a size of antenna, the main beam diameter is wide enough to obviate the need for an automatic tracking system. However, the antenna position can be varied in both azimuth and elevation, and the user has the option of a manual screw arrangement, or the possibility of remote control by use of motorised jack screws. The antenna movement is limited to ±25° azimuth and between 0 and 57° elevation; this should be quite sufficient, provided that the basic antenna site is in a south-facing position.

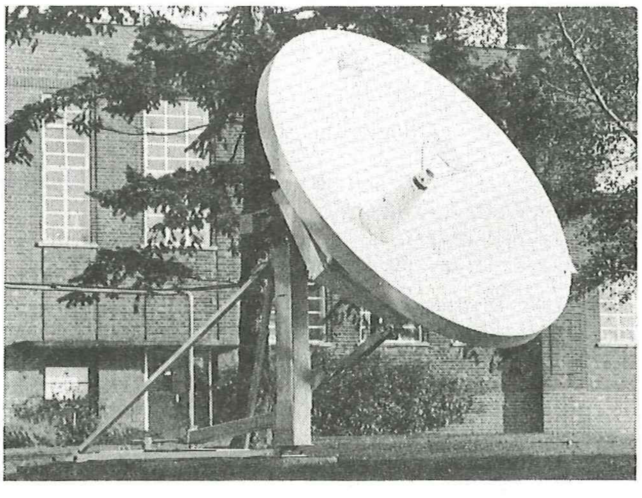

FIG. 2—The Antenna installation for Project UNIVERSE at the Marconi Research Laboratories, near Chelmsford, Essex

Equipment Cabinet

The internal equipment is mounted in a free-standing cabinet, which can be situated remotely from the computer facility. The overall equipment provides both upconverter and downconverter chains. (See Fig. 3).

Transmit Path

The signals between the data terminal and the computer facility are processed in an interface unit, which converts transistor-transistor logic (TTL) data signals into balanced differential signals for transmission to the computer; it also takes the balanced differential signals from the computer and converts these to TTL levels. This means that interconnection can be made to the computer at distances up to 100 m, using twisted-pair cables. In addition, DC status signals are converted to TTL levels and, thence, to a balanced differential form; also, power-level indication is processed for remote indication.

The processed signals to be transmitted at 1 Mbit/s are applied to a convolutional encoder, though the system allows direct application to the 2-phase modulator, if required, by operation of a front-panel switch. In order to eliminate phase ambiguities, differential coding is used.

The encoded signal spectrum is shaped by a channel filter before being linearly modulated directly on to the intermediate frequency (IF) carrier at 70 MHz. The system can operate in either continuous or burst-mode operation. In burst-mode operation, the *burst control* signal switches the carrier ON or OFF. During OFF periods, the output level control is disabled and a track-and-hold facility prevents the output stage gain from going to maximum; thus, high noise output is prevented during OFF periods.

The modulated carrier is applied to a double upconverter unit, where it is converted to the 14 GHz band, with a first IF of 770 MHz and local oscillator at 700 MHz. The second local oscillator can be switched between 2 frequencies by switching reference oscillators. The unit provides an indication of lock status for the local phase-locked oscillator (PLO).

The double upconverter output passes through a filter/circulator to an intermediate travelling-wave amplifier (TWA), which raises the transmit level to 10 W. This output is then applied to a second TWA, which raises the transmit level to 140 W. The power output can be controlled and monitored, both at cabinet level and from a remote position. The transmit signal is applied to the antenna feed via a circulator and waveguide switch to allow disconnection from the feed when required.

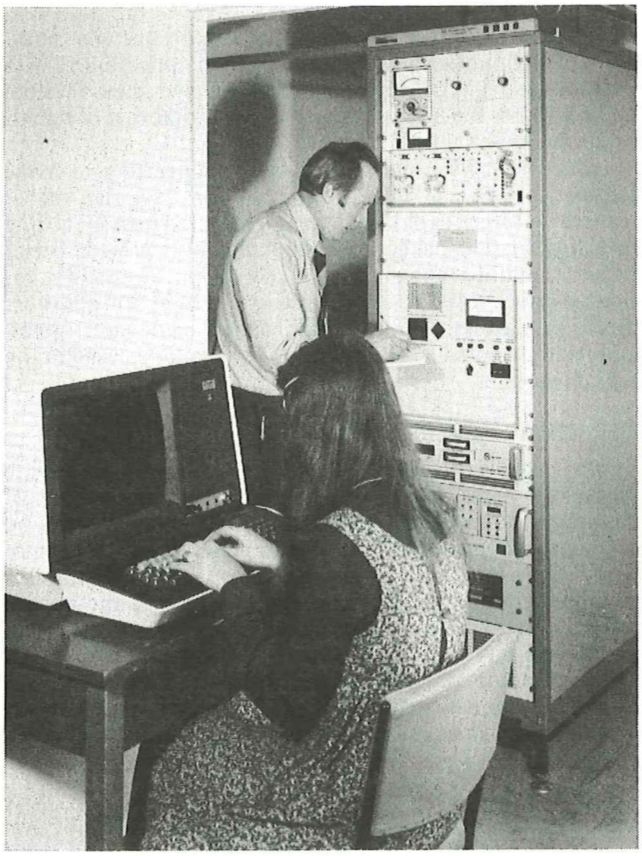

FIG. 3—View of the equipment cabinet for Project UNIVERSE

Receive Path

The signal from the satellite is fed directly to a field-effect transistor amplifier, having a bandwidth of 350 MHz, a gain of 25 dB and a noise figure of 2·5 dB. The amplifier output is fed through a waveguide switch, which allows the received signal to be filtered and connected to the receive downconverter, or allows the test translator output to be used for checking the receive system without accessing the satellite. The 11 GHz signal is applied to a double downconverter module, which processes the signal to produce a 70 MHz IF output at a level of −25 dBm. The PLO status is displayed on the front panel.

The downconverter output is fed to an interface module and to a directional coupler, where the signal is split into 2 paths.

One path feeds a signal monitor module, which processes the signal before applying it to a receive power monitor. The filter in the signal monitor module is specially calibrated for noise bandwidth, and for carrier power loss when the carrier is modulated with a pseudo-random sequence. Thus, the link performance can be checked and the unit can be used for carrier-to-noise ratio measurements.

The other path feeds the demodulator module to permit the data and clock information to be recovered from the received signal. In burst-mode operation, this has to be accomplished within a specific number of bits from the start of the burst. The design of the demodulator is therefore a compromise between rapid acquisition and loop bandwidth. The input amplifier provides not only signal amplification, but also automatic gain control, which gives a constant amplitude signal to the frequency-lock loop used to remove frequency errors from the incoming signal bursts. The signal is demodulated to baseband, filtered, and then upconverted for carrier recovery and coherent demodulation. The demodulated signal has then to be regenerated and decoded. The demodulated baseband signal is applied to a 3 bit analogue-to-digital converter, which produces a soft-decision signal suitable for application to the codec unit.

NETWORK INTERCONNECTION

One of the purposes of Project UNIVERSE is to determine the most effective means of connecting the various networks. Four types of gateway or bridge will be required:

(*a*) a bridge between the satellite earth terminal and the communication ring;

(*b*) a bridge between the site rings;

(*c*) a bridge connecting the network (that conforms with CCITT Recommendation X25) with the communication ring;

(*d*) a bridge between the University College ring and the high-speed terrestrial link to Logica. (This is known as a *terrestrial half-bridge*.)

The required bridges are either under development or in current use in local area communication networks.

NETWORK CONFIGURATIONS

Satellite

The satellite network is the part of the system that interconnects the various communication rings at separate locations. The network comprises a satellite, in this case the OTS, a ground station to receive and transmit the data, and an interface between the ground station and communication ring.

The ground station is similar to that used in previous OTS experiments. The interface comprises 2 parts. The first part is a satellite interface module, using a Motorola 6800 processor; this processes the data stream to and from the ground station, which involves performing the multiplex/demultiplex function, synchronisation, timing and framing. The second part is a link-driving computer, which performs the packeting function. The computer, a GEC 4065 with 512 Kbyte of buffer store and two 4·8 Mbyte discs, interfaces directly with the communication ring. One of the purposes of the UNIVERSE experiment is to gather information on the data rates that can be achieved through the link-driving computer.

The space segment data packets have a frame size of 125 ms, with the frame containing slots for the use of each transmitting earth station. The allocation of a data slot, in each frame, is made by the master ground station.

Communication Ring

The need for interconnection of computers positioned close together at each location has resulted in a considerable amount of work to find the most efficient means of communication between them. Various systems have been developed, such as Ethernet and the Cambridge Ring; for Project UNIVERSE, however, the Cambridge Ring system has been adopted, although at least one alternative system is also being used to maintain the generality of interconnection protocols. A typical system is shown in Fig. 4.

The Cambridge Ring, as its name implies, was developed at Cambridge University from 1974 onwards. It comprises a communication system, in the form of a ring, running round a number of buildings to connect, in a general way, a number of computer facilities.

The basic data rate is 10 Mbit/s. At each facility, a station is connected to the ring through an access box or repeater. Messages are passed from source to destination in the form of a number of discrete mini-packets. Mini-packets, which are 38 or 40 bits long, circulate continuously around the ring; when a station has a message to transmit, it seizes free mini-packets by flagging them as full, loads the next part of the message string, and adds the source and destination addresses. All stations monitor the destination address block and, when there is a match, the data is removed and receipt acknowledged. The mini-packet circulates back to the source, which checks various housekeeping bits, and releases the mini-packets. Control bits indicate the behaviour of the recipient; for example, *data received OK*, *busy*, *off-line*. Depending on the messages, the source continues to seize mini-packets, as available, until the whole message is delivered.

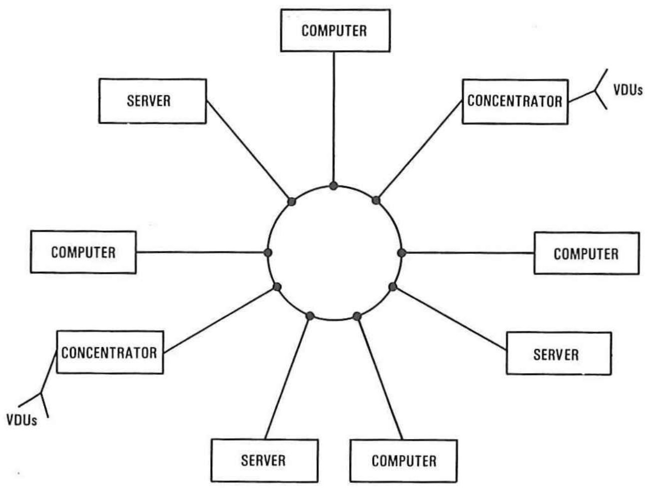

FIG. 4—Layout of a typical Cambridge Ring system

The ring has not only computers connected to it, but also a variety of servers. Terminal servers use Z80A or 8080 microprocessors for concentration, which allow a number of visual display units (VDUs) to be connected to one station. The ring is managed by another server called the *resource manager*, which allocates a computer, or computers, to the user, and routes the user to other server functions such as file access, printing facilities, time signals, etc.

Project UNIVERSE will include definitions of system protocols with the aim of achieving a common set throughout the network. This standardisation is necessary to prevent incompatibility between systems and, hopefully, will lead to international agreement on interfaces and protocols. The importance of this cannot be stressed too much, if the growth of world-wide data communications by satellite is to take place in a trouble-free manner.

Terrestrial Links

An area of great interest for future high-speed data business systems is the use of high-speed terrestrial links as tails from a satellite-communication facility over short distances. Although the use of satellite communication removes the need for long-distance terrestrial links, it is still necessary to connect data terminals on each communication ring. It is therefore part of the UNIVERSE experiment to look not only at new methods of interconnection, such as optical fibre, but also at existing methods using cable and available modems.

Loughborough University is to investigate the characteristics of a communication ring wired with optical fibre, with paths up to 1 km in length. This will involve some development work for the multiplexing and demultiplexing of signals on to the fibre.

In London, UCL and Logica are co-operating to make Logica part of the UCL ring and, for this, the use of transverse-screen cables over several hundred metres is being investigated. The helical form of screen may provide better noise immunity and improved screening capability for twisted-pair cables at lower cost and weight. In addition, this form of cable will be used for connection of ring bridges, and for transmission of standard PCM signals as used in the BT network.

THE UNIVERSE PROGRAMME

There have been several experiments relating to satellite business systems, mainly concerned with the mechanics of communication and the feasibility of the space and ground segment equipments. With the imminent implementation of the ECS system, and the availability of the satellite multi-services transponder, it is necessary to look at the system implementation as a whole. This is the main aim of Project UNIVERSE.

The business communication system includes the satellite link, the local network systems and wide area networking. The questions to be asked and equipment to be looked at are as follows:

(*a*) What internal functions should be provided, how should they operate under different information loads and how easy is it to use the system?

(*b*) What equipment designs should be used for network interconnection, including multiplexers/demultiplexers on

optical-fibre links, high-speed modems and computer interface systems?

(*c*) What data bearer systems are required?

(*d*) What are the system design requirements to accommodate the effect of the large delay on the satellite link?

(*e*) How can the satellite TDMA system be improved?

(*f*) How can the Cambridge Model Distributed System design be improved with regard to coding, packet size error, correction, security procedures etc.?

(*g*) What types of service can be handled—voice, data transmission, teleconferencing?

In addition, the project will try to identify the forward development requirements of a business communication system. It is necessary to use, wherever possible, current equipment that is well proven and requires no extra capital expenditure to make it fit the system. However, new systems will undoubtedly require the development of new equipment to cater for the problems found under operational conditions. Project UNIVERSE will also address these problems. In particular, it will review:

(*a*) satellite earth station (SES) terminal equipment,

(*b*) SES control and monitoring, and

(*c*) terminal equipment for the communication rings.

FUTURE DEVELOPMENTS

Project UNIVERSE will provide a considerable amount of information on the operation, monitoring and equipment requirements of a high-speed data network. Through work carried out over a 2–3-year span, there will be many pointers towards future requirements, both in terms of equipment and of network procedures. The project will be invaluable in that it is oriented towards a practical realisation of a communication system that will be required in the near future. From the point of view of the equipment manufacturer, identification of future needs is most important because of the time lag involved in development of equipment through to full production.

Current experience shows that a network cannot achieve financial viability purely from the dissemination of high-speed data. It must also be able to provide a wide variety of services to any prospective customer. It is essential that any system should appeal to as many potential users as possible. To this end, the network should provide voice as well as all the possible services associated with data transmission, such as bulk data transfer, video transmission, teleconferencing, teletext, and image transfer.

The need for maximum system utilisation to obtain financial viability brings with it a dilemma. Greater diversity implies more complex terminal equipment and, consequently, higher costs; this would lead to higher customer resistance to the use of satellite earth terminals and it could, therefore, end in lower system utilisation.

To ensure maximum take-up of the facility, the following factors should be taken into account.

(*a*) The system should not be over-specified. Authorities involved in controlling and specifying terminal equipment must recognise that to over-specify will simply increase costs and may well reduce demand.

(*b*) The terminal user will not be interested in the extent of the use of state-of-the-art components. He is interested in equipment that will fulfil the basic system parameters.

(*c*) The terminal should consist of a basic equipment that provides the necessary functions, but capable of expansion by means of plug-in modules to add extra facilities as required.

(*d*) Supervisory and monitoring functions should be simple, though it will probably be necessary to provide remote supervision facilities, either at a computer facility or within an apartment or office block, depending upon the user's premises.

(*e*) Maintenance must be simple.

(*f*) Initial terminal costs must be low.

(*g*) Regulatory controls on terminal use must be kept to a minimum. The user must feel that he can easily change his terminal function, without having to become involved in complicated bureaucratic procedures.

The possibilities inherent in the type of system being investigated in Project UNIVERSE are tremendous. Experience in the USA has shown that benefits to companies having a number of establishments remote from one another can be enormous in terms of lower cost and improved facilities. It has also shown that, for those benefits to be realised, and for networks to grow, 2 main factors are necessary. Firstly, the system must provide the widest range of facilities; it must not concentrate purely on high-speed data services. Secondly, the market place should not be restricted by external authority. Any external controls should be concerned mainly with technical performance, and not be involved in dissemination of network equipment.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. D. King of Marconi Research Centre for his assistance in the preparation of this article.

References

[1] Ackroyd, B. R. Satellite Communications, Project UNIVERSE and Local Area Networks. *Communication & Broadcasting*, Feb. 1983, **8**(2), pp. 3–8.

[2] Bowsher, B. D. New Digital Transmission Services for the Business Community. *ibid.*, Feb. 1982, **7**(2), pp. 3–10.

[3] Wooster, C. B. ECS—The European Communication Satellite System. *ibid.*, Sept. 1981, **7**(1), pp. 39–47.

[4] Smith, D. Towards a Satellite-Based Data Network for Europe. *ibid.*, Apr. 1980, **5**(3), pp. 3–14.

[5] Nippierd, V. L., and Watson-Lee, M. A. S. Ground Communications Equipment for Large Earth Stations. *ibid.*, Mar. 1981, **6**(2), pp. 43–49.

Thames Barrier Communications

R. W. LONG†

UDC 621.39:627.51

This article describes the provision of the communications network for the new flood barrier that has been constructed across the River Thames in London.

INTRODUCTION

The Greater London Council (GLC) has built the world's largest movable flood barrier across the River Thames at Woolwich, in south-east London, to help protect London from the threat of a major flood disaster. A vital part of the barrier project is the complex communications network that is being provided by British Telecom (BT) and is nearing completion. This network will enable staff in the barrier control room to be informed of impending flood threats, to monitor flood control systems and to keep in touch with emergency services.

† British Telecom London South East

FIG. 1—Thames barrier
(Photograph by courtesy of the Greater London Council)

THE FLOOD THREAT

For centuries Londoners have lived under the threat of serious flooding from the River Thames. The flood threat has several continuing factors. Britain is slowly tilting, so that London and the south-east of England are dipping downwards at the rate of about 30 cm every century. Also, London is steadily sinking on its clay base and high tides are getting higher—today's high tides at London Bridge are more than 60 cm higher than they were 100 years ago.

A special threat arises from the possibility of surge tides, caused by bad weather conditions in the North Atlantic and North Sea, being funnelled up the Thames Estuary. Such a surge on top of an already high tide could cause severe flooding in large areas of central London with disastrous consequences.

The building of the barrier, together with other major flood defence works which are being carried out upstream from Battersea and Hammersmith and downstream to the estuary, will provide long-term protection against this threat.

THE THAMES BARRIER

The barrier spans 570 m from bank to bank and consists of 10 steel gates supported between concrete piers (see Fig. 1). The 4 main gates, each 61 m in length and 3200 t in weight, and 2 smaller gates, each 31·7 m in length and 900 t in weight, are based on the rising-sector gate principle (see Fig. 2). The gates are convex in section and are normally recessed in concrete sills on the bed of the river, allowing shipping to pass. To close the barrier, the gates are turned through 90° by hydraulic systems installed in the pier housings (see Fig. 3). Four radial gates, each weighing 220 t, complete the barrier.

The barrier control building on the south bank houses the communications room where cables from telephone exchanges on the north and south banks are terminated and the line-termination racks and gas-pressurisation equipment for the cables are installed. The service tunnels that carry BT cables across the river are built into the barrier piers and continued through the gate housings which lie on the bed of the river. These tunnels can be seen in Fig. 3.

COMMUNICATIONS REQUIREMENTS

Negotiations with the GLC and their consultants—Rendel, Palmer and Tritton—on the provision of communications facilities for the barrier began in 1980.

The GLC's requirements were for the provision of

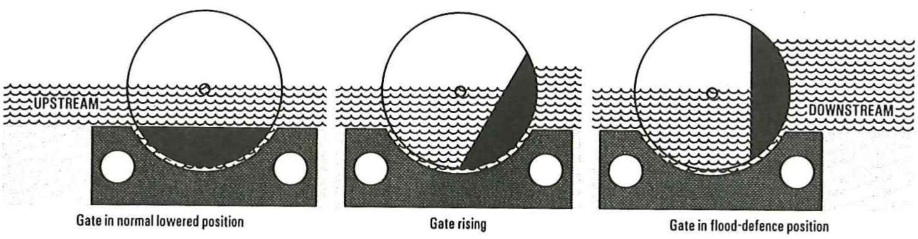

FIG. 2—Rising-sector gate principle

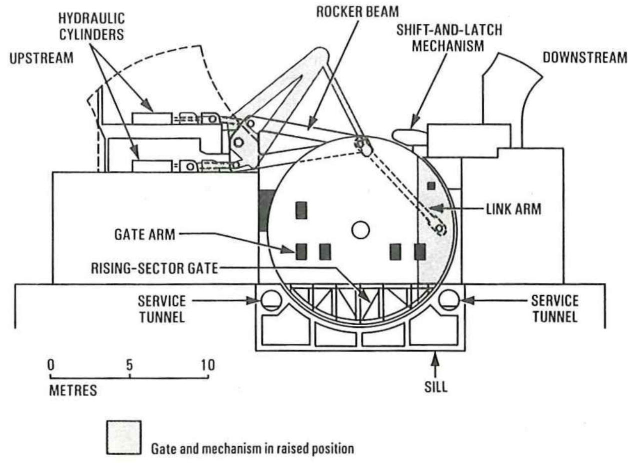

FIG. 3—Operation of rising-sector gate

(*a*) internal communications at the barrier site;

(*b*) dedicated cables to exchanges outside the flood-risk area on the north and south banks;

(*c*) a network of data, telemetry and audio private circuits to various locations in London and the south-east of England; and

(*d*) exchange lines to exchanges on the north and south banks, other than those terminating the dedicated cables, to provide alternative communications links in the event of failure of the above cables.

It was emphasised that all the circuits to the barrier were essential to its operation, and so every precaution had to be taken against their failure.

CABLE DESIGN

The GLC's requirements specified at the early planning stage were for 200 pairs to the south bank and 300 pairs to the north bank. BT proposed that 100-pair cables be used to decrease the risk of complete failure in the event of a cable being damaged, and that the cables be terminated at Albert Dock exchange on the north bank and Greenwich exchange on the south bank. These exchanges were chosen because they were situated outside the flood-risk area and had extensive networks for connecting private circuits.

However, there was a major problem with the provision of the cables to the Albert Dock exchange. The cables were to be routed from the south bank to the north bank by means of the service tunnels built under the barrier piers. BT was asked to install 2 cables in the upstream tunnel and one in the downstream tunnel, and to use cables with a sheath material that would produce minimum smoke and toxicity in the event of fire breaking out in the tunnels.

Although cable with sheath material meeting these requirements was available, the problems of jointing it to the standard polyethylene-sheathed cable that was to be used from the north bank to the Albert Dock exchange had not been overcome. To guard against the possibility of failure of one of the lengths through the tunnel, BT would have had to hold stocks of this non-standard cable and instruct jointing staff on the methods of installing and jointing the cable. The training of new staff would have been an ongoing expense.

The solution finally agreed was to take standard polyethylene cable through the tunnels, and for the GLC to install steel trunking to protect the cables in the event of fire. Fig. 4 shows a cross-section of the upstream tunnel with the steel trunking installed.

CABLE PROTECTION

The alternatives of using jelly-filled or gas-pressurised cables were considered, and the jelly-filled cable discarded, the main reason being that if the sheath was damaged, no

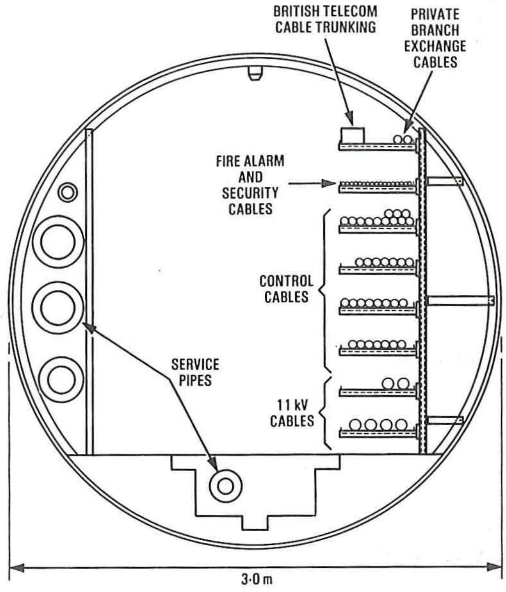

FIG. 4—Cross-section of upstream cable tunnel

warning that a fault condition existed would be given until a circuit failed.

However, the application of pressurisation to the cables presented a further problem. As the cables to the Albert Dock and Greenwich exchanges were over 7 km and 5 km in length, respectively, they presented a high pneumatic resistance to the air being fed from the gas-pressurisation equipment at the exchanges. The lowest pressure would be at the barrier, where the greatest risk from water damage existed. It was therefore decided to install a second gas-pressurisation installation at the barrier control tower in the level-5 communications equipment room.

BT was completing the development of self-contained compressor and desiccator equipment, known as *Compressor-Desiccator Unit No. 1A (CDU 1A)*. The unit

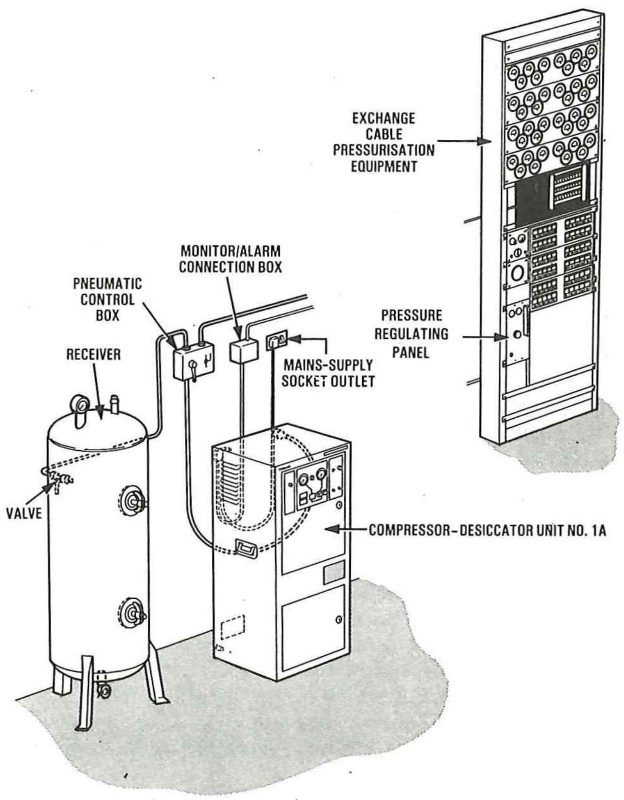

FIG. 5—Compressor-Desiccator Unit 1A installation

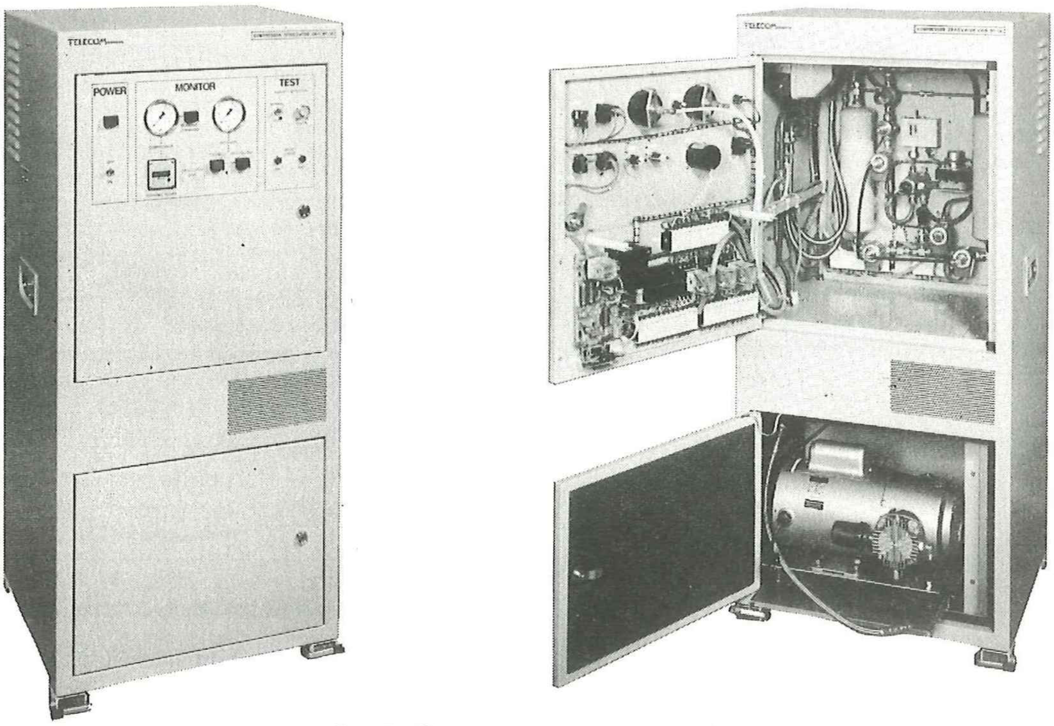

FIG. 6—Compressor-Desiccator Unit 1A

was ideal for installation at the barrier as it is smaller, less noisy and more compact than conventional equipment, since the compressor, desiccator and humidity detector are housed in a single cabinet and the compressor is sound proofed. Fig. 5 shows the layout of this equipment with the dry-air receiver, compressor, desiccator and exchange cable pressurisation rack. Fig. 6 shows the internal arrangements of the CDU 1A; the compressor is housed in the lower cabinet.

The CDU1A supplies the receiver and operates only when the pressure in the receiver falls below a specified level. The size of the receiver can be changed to give the desired reservoir of air to maintain pressure if the unit should fail. A receiver having capacity to maintain pressure for 24 h under normal conditions was chosen for the unit installed at the barrier. This was thought to be sufficient as stand-by generators were installed at the barrier to maintain power feeds, and unit alarms were to be fed to Greenwich exchange and GLC control points. The following conditions are monitored and alarmed: mains supply, compressor run command, humidity level, receiver contents and compressor output pressure.

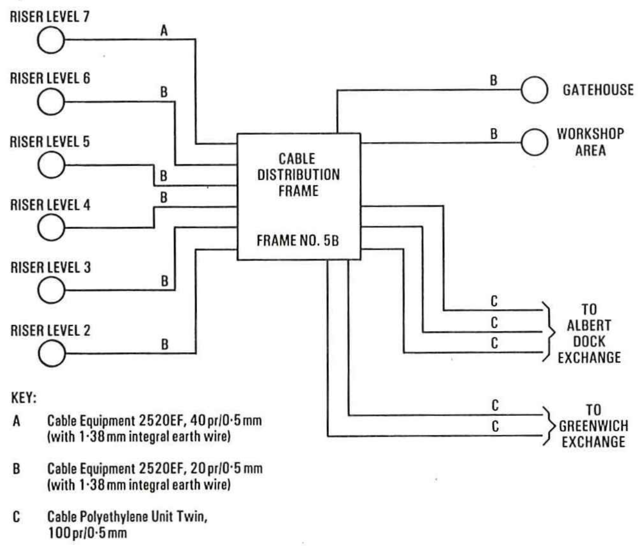

FIG. 7—Cable-distribution frame

PRIVATE-CIRCUIT NETWORK

Table 1 lists the private circuits ordered by the GLC. The tide-gauge circuits, which use telemetry at 50 bauds, give information on water levels. The flood-prevention indicator circuits give information on the position of the emergency flood gates protecting various premises on the downstream side of the barrier. These gates must be closed to prevent flooding when the barrier is operated.

The emergency speech circuits provide links to centres where action could be required should flooding occur. The GLC is at present proposing that these circuits carry a data channel in addition to speech with the frequency band divided between speech and data channels at 2000 Hz. BT has suggested that this be moved to 2500 Hz to accommodate the Signalling System AC No. 15 signalling frequency of 2280 Hz. It is possible that, when details of the type of data link to be provided are known, the circuits will have to be upgraded.

The circuits to the Meterological Office at Bracknell are the most essential to the operation of the barrier. The 2-wire circuits connect the barrier with the Storm Tide Warning Service, which gives information on the state of tide gauges on the east and south coasts of England, and provide emergency speech services. The 4-wire data circuits provide the latest information on weather conditions from the Meteorological Offices's computer. Because of the importance of these circuits, main and stand-by circuits, one routed via the north bank and the other by the south bank, are being provided on each link. Methods of switching to stand-by circuits have still to be decided.

INTERNAL COMMUNICATIONS

Internal communications in the control building will be provided by a Herald system, and throughout the remainder of the barrier site by a privately-purchased private automatic exchange. The cables from Albert Dock and Greenwich exchanges have been terminated on an internal cable distribution frame (Frame No. 5B) installed in the level-5 communications room from which 20-pair cables with integral

TABLE 1
Private Circuits

Circuit Type and Radial Distance	Location of B-End (A-end at barrier control room unless otherwise stated)	Description of Outstation
2-wire 12·8 km	London Fire Brigade Headquarters, London	Emergency speech
4-wire 16 km	GLC County Hall, Westminster, London	IBM 3033 computer
2-wire 7 km	Bow Creek Barrier, Canning Town, London	Emergnecy speech
2-wire 8 km	Thames Water Authority, Crossness Sewage Treatment Works, London	Emergency speech
2-wire 0·2 km	Port of London Authority Barrier Control Room, Woolwich, London	Emergency speech
2-wire 1·2 km	Albert Dock, London	Tide gauge and emergency speech
2-wire 1·6 km	GLC Woolwich Ferry (south bank)	FPI
2-wire 7·4 km	Tower Pier, London	Tide gauge
2-wire 16 km	Chelsea Bridge, London	Tide gauge
2-wire 9·6 km	Belvedere, Kent	FPI
2-wire 32 km	Port of London Authority, Gravesend, Kent	Emergency speech
2-wire 32 km	Twickenham, Surrey	Tide gauge
2-wire 40 km	Southern Water Authority, Chatham, Kent	Emergency speech
2-wire 1·6 km	GLC Woolwich Ferry, London (north bank)	FPI
2-wire 1·6 km	North Woolwich, London (see note 1)	FPI
Two 2-wire (see note 2) 58 km	Storm Tide Warning Service, Meteorological Office, Bracknell, Berkshire	Emergency speech and east and south coast tide gauges
2-wire 12 km	Thames Water Authority, Beckton Sewage Treatment Works, London	Emergency speech
Two 4-wire (see note 3) 58 km	Meteorological Office, Bracknell, Berkshire	IBM 370/15B computer
2-wire 0·8 km	Silvertown, London	Tide gauge and FPI
2-wire 50 km	Sheerness, Kent	Tide gauge
2-wire 43 km	Southend Police Station	Southend warning bell
2-wire 1·2 km	Charlton, London	Tide gauge
2-wire 12·8 km	Erith, Kent	FPI
2-wire 39 km	Anglia Water Authority, Chelmsford, Essex	Emergency speech

FPI: Flood prevention indicator
Notes: 1 The A-end of this circuit is Woolwich Ferry (north bank). Signals from this circuit are transmitted over the circuit shown immediately above.
2 Circuits operated in parallel; that is fitted with a hybrid at both ends and an alarm at the barrier end to indicate when a circuit fails.
3 One duty and one stand-by circuit capable of being switched at the modem if the duty circuit fails.

earth have been taken to distribution points (DPs) in the main riser at each floor (with the exception of level 1, which had no telephone requirements). DPs have also been provided in the gatehouse and workshop area for the emergency-telephone links to Woolwich (see Basic Requirements, item (*d*)). Fig. 7 shows the cabling arrangements.

The GLC will be installing conduits from the DP position in the riser to each telephone, the telephone leads in the conduits and the telephone outlet plates.

CONCLUSION

At the time of writing, the cables to Greenwich and Albert Dock exchanges, the local gas-pressurisation equipment, the line-termination rack for the private circuits and the internal cable distribution frame have all been installed.

Several problems with the private circuits, including the possibility of upgrading emergency speech circuits and the change-over methods for the circuits to Bracknell, still have to be resolved. Several problems with the installation of the B-ends of private circuits have been experienced. In many cases these are in the middle of factory and dock complexes, creating difficulties with cable routes and wayleaves. As no overhead plant could be used, it has been necessary to install ducts in expensive materials such as re-inforced concrete and engineering brickwork.

However, it is anticipated that despite these problems the project will be completed in the near future.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the help given by staff in the External Plant Development Division of British Telecom Inland Division and External Planning Groups of British Telecom London East during this project.

Institution of British Telecommunications Engineers

(formerly Institution of Post Office Electrical Engineers)

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(Membership and other local enquiries should be directed to the appropriate Local-Centre Secretary as listed in the October 1982 issue)

Mr. J. S. Whyte, C.B.E., M.SC.(ENG.), F.ENG., F.I.E.E.

Mr. D. Wray, B.SC., F.ENG., F.I.E.E.

RETIREMENT OF MR. J. S. WHYTE

John Whyte has been such a prominent member of the British Telecom (and British Post Office) senior management team for so long that it is difficult to grasp the fact that he has now retired and is therefore no longer the President of our Institution.

Mr. Whyte has been a pioneer in almost every phase of his career. In his work at the Castleton Radio Laboratories he developed some of the earliest microwave radio systems, including the white-noise test equipment. He was a pioneer in pulse-code modulation transmission techniques at Dollis Hill. He energetically introduced computers and systems analysis techniques in Government departments during his spell at the Treasury O&M Department. And upon his return to head the Long Range Studies Division he was responsible for the studies which led to the digitalisation of the network and laid the foundation of System X.

Since then he has been Director of Operational Programming, Director of Purchasing and Supply, Senior Director of Technology and has concluded his career at the very peak of the engineering hierachy as Managing Director of Major Systems and Engineer-in-Chief.

He has long been interested in other peaks as well. A noted climber of hills and mountains, he led an expedition into the Himalayas which brought back some fascinating evidence of their mysterious inhabitants. He has combined this with an active participation in the Royal Institution, the Institution of Electrical Engineers and the Fellowship of Engineering. For John Whyte every day contains 48 action-packed hours.

Mr. Whyte has been President of our Institution since 1977 and members who have attended the AGM will have treasured his cool and lucid analysis of the problems and promises which lay ahead. He has been a tower of strength to the Institution in his enthusiastic support and his vigorous representation of our interests on the Main Board of British Telecom.

All members will wish him a happy and active retirement.

D. WRAY.

CHAIRMAN OF THE IBTE COUNCIL

Donald Wray, recently appointed as Assistant Managing Director Broadband Services to promote and co-ordinate British Telecom's (BT's) interests in cable television and local broadband services, completed his 3-year term as Chairman of the IBTE Council and the Board of Editors of this *Journal* in May 1983.

Donald has had a very keen and long-standing interest in Institution affairs; before his appointment as Chairman of Council he was a Vice-Chairman for 13 years during which time he also chaired its General Purposes and Finance Committee. More changes have had to be accommodated under his period of leadership than ever before in the Institution's 77-year history, the principal outward sign being the new title which took effect from April 1982. Throughout this period he has displayed his unfailing good humour and sound commonsense to good effect, and I can do no better than repeat what he wrote of his predecessor, Frank Thomas, in 1980, that 'he has coaxed and cajoled Council into flights of unsuspected imagination'. All Institution members and especially those who have served under him on Council and the Board of Editors wish him well in his new post.

John Boag, BT's Chief Executive Trunk Services, has accepted our President's invitation to succeed Donald as Chairman of Council.

A.B. WHERRY
Vice-Chairman of Council

HONORARY MEMBERSHIP

The following have been elected to Honorary Membership in recognition of their considerable services to the Institution over many years:

Mr. D. Wray, former Chairman and Vice-Chairman of Council;

Mr. N. Fox, retired, former President of the Associate Section and Chairman of Stone/Stoke Centre; and

Mr. A. G. Leighton, retired, past Managing Editor of the *Journal*, Member of Council and Chairman of Library Committee.

CONSTITUTION OF THE COUNCIL FOR 1983–84

Chairman	Mr. J. F. Boag, Chief Executive Trunk Services, National Network Services, BT Inland.
Vice-Chairmen	Mr. A. B. Wherry, Chairman of BTNW.
	Mr. D. V. Davey, Chairman of NE Postal Board.

Elected Members (Rule 18 defines Group representation):

Mr. I. G. White, Honorary Treasurer.
Mr. D. A. Spurgin, representing Group 1.
Mr. R. E. Burt, representing Group 2.
Mr. G. E. Wilcox, representing Group 3.
Mr. D. Bull, representing Group 4.
Mr. B. Rowlands, representing Group 5.
Mr. P. Walling, representing Group 6.
Mr. E. Marmion, representing Group 7.
Mr. K. Coxey, representing Group 8.
Mr. T. K. Ray, representing Group 9.
Mr. D. Mallows, representing Group 10.
Mr. R. C. Taylor, representing Group 11.
Mr. C. Stanger, representing Group 12.
Mr. G. A. Gallagher, representing Group 13.
Mr. K. Moore, representing Group 14.
Mr. K. Chinner, representing Group 15.
Mr. L. Thomas, representing Group 16.

Under Rule 25, the seats for groups 3, 4, 5, 12, 13, 14 and 15 became vacant this year. Messrs. Wilcox (Group 3), Bull (Group 4), Stanger (Group 12), Gallagher (Group 13) and Moore (Group 14) were elected by virtue of being nominated unopposed. The seats for Groups 5 and 15 were contested, the unsuccessful candidates in descending order of votes cast being as follows:

Group 5	Messrs. D. J. Pink, D. J. Pike, A. Gray and J. W. Larke.
Group 15	Messrs. D. M. Birch, E. R. M. Sutherland and J. F. Saner.

FITCE CONGRESS AND GENERAL ASSEMBLY

The 22nd Annual FITCE Congress and General Assembly will take place in Madrid from 19–24 September 1983. Members requiring further details should contact the Secretary or Mr. P. A. P. Joseph, Assistant Secretary (FITCE) (Telephone: 01-588 8970).

R. E. FARR
Secretary

IBTE CENTRAL LIBRARY

The books listed below have been added to the IBTE library. Any member who does not have a copy of the 1982 edition of the library catalogue can obtain one on loan from The Librarian, IBTE, 2–12 Gresham Street, London EC2V 7AG. Library requisition forms are available from the Librarian, from Local-Centre and Associate Section Centre Secretaries and representatives. The form should be sent to the Librarian. A self-addressed label must be enclosed.

5343 *The Viewdata Revolution.* S. Fedida and R. Malik (1980).

This book discusses the workings of viewdata and its impact on society. It mainly deals with the Prestel system which Sam Fedida worked on at British Telecom Research Laboratories.

5344 *Pascal for Programmers.* S. Eisenbach and C. Sadler (1981).

This is an introduction to the Pascal programming language for those who are already familiar with other languages.

5345 *The Nuclear Apple and Solar Orange.* M. Grenon (1981).

This book is a non-technical discussion of future energy needs.

5346 *Understanding Computers — what managers and users need to know.* M.E. Walsh (1981).

This is a book on computers, written for the lay-person by a computer expert, giving in-depth coverage of computer basics.

5347 *Introduction to Electric Circuits,* fifth edition. H.W. Jackson (1981).

This book provides a thorough grounding in basic electric circuit theory.

5348 *Fundamentals of Electronics,* third edition. E.N. Lurch (1981).

This book is intended to provide technicians working in the field of electronics with a firm foundation from which they can study more specialised aspects of electronics.

5349 *Understanding Microprocessors.* L. Rich (1981).

A step-by-step approach is used to explain a variety of microprocessor operations.

5350 *System Design Using Integrated Circuits.* B.S. Sonde (1981).

Beginning with an introduction to integrated circuits (ICs), the book goes on to describe in detail basic digital and linear ICs together with some of their applications. The characteristics and limitations of various ICs are also discussed.

5351 *The Making of the Micro.* C. Evans (1981).

This book records the fascinating history of the microprocessor.

5352 *Electronic Communications.* D. Roddy and J. Coolen (1981).

Communications fundamentals, circuits, modulation, transmission and systems are covered in detail, but the level of treatment presupposes a broad knowledge of electronics, mathematics and basic electric circuits.

5354 *Thyristors — theory and applications.* R.K. and K.K. Sugandi (1981).

5355 *Tunnels — planning, design, construction,* Vol. 1. T.M. Megaw and J.V. Bartlett (1981).

This book examines the range of uses and construction techniques for bored tunnels in soft ground and rock.

5356 *Practial Troubleshooting Techniques for Microprocessor Systems.* J.W. Coffron (1981).

This book provides a lucid user-orientated text that emphasises a simple and inexpensive approach to effective microprocessor-system troubleshooting.

5357 *Microprocessors for Engineers and Scientists.* G.A. Gibson and Y.C. Liu (1981).

P.W. SALTER
Librarian

British Telecom Press Notices

BRITISH TELECOM INTRODUCES A NEW RADIOPAGER

British Telecom (BT) has introduced Britain's first wide-area radiopager with a message display. A 10-digit liquid-crystal display on the new pager can be used to identify the caller (by giving a telephone number), or to convey a message. The last 2 messages are stored in its memory and can be displayed at the touch of a button.

Like a tone pager, the new version gives a distinctive bleep to alert users; it also has a tiny lamp that flashes in response to a call, a facility that enables users to be alerted even when the bleep is muted to avoid disturbing others.

Display Page, the name given to BT Radiopaging's new service, for the first time makes it practical for customers to advertise their paging numbers so that anyone can call them.

With BT's existing Tone Page service, which has been in operation since 1976, each pager number is usually known only to a few people. When paged, the user has to respond by calling a prearranged number to find out who has been trying to make contact with him. With Display Page, however, anyone can make a call to the pager. Calls are made by dialling a London number and giving an operator the pager number and a numerical message to be displayed in the window of the pager. The message can be any combination of figures from 0 to 9. It may be a telephone number or a prearranged code. The letter U can also be included (to indicate urgency, for example), plus bracket and dash symbols.

Display Page, available initially in south-east England—from Ipswich to Chichester—is being progressively extended to other parts of the country.

Additional bleep tones can be provided, without a display, to enable the pager to respond to a call in all parts of the UK covered by BT's Tone Page service. Later this year, callers will be able to put in messages direct without the help of an operator. It is expected that the display capability will eventually be extended to include all the letters of the alphabet as well as numbers.

FIRST ELECTRONIC OFFICE PRODUCTS FROM MERLIN

The electronic office has come a step nearer since the introduction of British Telecom (BT) Merlin's first products in office automation earlier this year. The new systems comprise a personal computer, a word processor, communicating visual-display unit (VDU) terminal, and printers.

This new venture into automated-office equipment is based upon 5 principles:

(*a*) commitment to proven technology, with evolutionary potential;
(*b*) open systems, simplifying communication between different machines;
(*c*) user friendliness, to make for ease of use;
(*d*) first-class service and software back-up; and
(*e*) value for money.

Although, the range of equipment has significant new performance features, BT Merlin is not just offering hardware but also is augmenting the comprehensive service it aims at providing for its business customers. As communications and computer technology become more integrated, it makes sound commercial sense for BT to extend its presence in the information-technology market by offering office-automation terminals and software; and it almost goes without saying that BT should provide this equipment with comprehensive communications capabilities.

Moreover, BT has a proven track record in computer communications going back more than 20 years, and, as Europe's largest computer user, a wealth of experience in data processing. Also, BT has been one of the world's pioneers in information technology with the invention of Prestel and Confravision. It offers the business community some of the world's most advanced communications equipment and systems; for example, the Monarch digital microchip office switch, text-editing electronic teleprinters, and the mailbox service, Telecom Gold.

The new Merlin office-automation products, which are being supplied by ICL plc, represent a modest beginning in a different sector of information technology. BT's main aim with this new venture is to establish a nationwide sales and maintenance service that will be completed by the end of this year, and to establish some worthwhile sales.

The star of the new range of equipment is the M2226 small business computer. It provides 5 Mbytes of memory, Winchester disc-drive storage and 800 Kbytes on floppy disc. It has a wide range of communications options that enables the user to gain access to private and public databases at the touch of a button—the numbers are stored in the modem which provides automatic dial-up and log-on. The modem also means that the M2226 can, through the use of a computer-based message service such as Telecom Gold, send and receive messages; and linked to a Puma teleprinter, the M2226 becomes a Telex terminal.

The M2226 features Merlin Master user-interface software packages, including sales co-ordination, mailing list, business administration and financial modelling; and comes supplied with the WordStar word processing package, and a choice of printers—a daisy-wheel printer for correspondence and 2 sizes of dot-matrix units.

Matching the M2226 is the M1100 desk-top VDU that uses the same modem as the M2226 to give automatic dial-up and log-on at the touch of a button. In addition to giving access to computer service bureaux, the terminal can also link into Prestel, Telecom Gold and other mailbox services, and the Packet SwitchStream (PSS) data service.

Merlin's M3300 communicating word processor completes the initial range. This offers press-button access to the Telex network, via a Puma teleprinter, and automatic dial-up to remote databases, computer bureaux, Prestel and electronic mail services. The angles of both keyboard and screen can be adjusted to suit the preference of individual operators. The M3300 has 256 Kbytes of storage on 2 floppy-disc drives to make it a powerful and versatile machine. For example, an operator can use short-hand codes, for long or tricky words to instruct the computer to change one particular word, where it occurs, throughout a text.

It can handle more complex formats—forms, columns (with or without rules), diagrams, flow charts, and newspaper layouts—and act as a calculator, to add, subtract, multiply, divide and work out percentages.

Customers will derive great benefit from the communications capabilities of BT's office automation products. Merlin is committed to the open-systems-interconnect principle, which means that customers will find it increasingly easy in future to operate systems using equipment of different makes and designs, based on common standards.

British Telecom Press Notices

DIRECT-DIAL CARPHONES FROM BRITISH TELECOM AND A NEW AUTOMATIC RADIOPHONE SERVICE FOR SOUTH-EAST ENGLAND

Automatic-radiophone sets, which enable motorists to make calls directly from their cars, supplied by British Telecom (BT) became available for the first time in April of this year. At the same time, BT's Automatic Radiophone service was extended to a new south-east zone as a first step in the creation of a national automatic network.

This new zone covers Peterborough, Norwich, Cambridge, Ipswich, Chelmsford, Southend and Canterbury; it also takes in the Solent-area service, started in 1981, which covers Bournemouth, Southampton, Portsmouth, and most of the Isle of Wight.

Automatic Radiophone, which was first introduced in London nearly 2 years ago, works more simply and quickly than carphone services in which calls are connected by operators. The user simply keys in the number on the telephone in the car and the call is automatically switched through to its destination. The radio technique used with manual services, such as remembering the PRESS-TO-TALK button, is eliminated.

Once connected, the automatic carphone functions just like telephones at home or at work. A user can make calls directly to any one of Britain's 30 million telephones or of the 430 million others available on international direct dialling to more than 125 countries.

The Automatic Radiophone service is being progressively introduced and will cover most of Britain by the end of the year. In addition to the south-eastern zone (which includes the Solent) and London, the other main zones will be:

(*a*) the Midland zone, ranging southwards and westwards from Stoke-on-Trent and Nottingham to embrace Milton Keynes, the Severn Valley, South Wales, Bristol, North Somerset, Taunton, Exeter, and Plymouth;

(*b*) the Northern zone, covering the conurbations on both sides of the Pennines northwards from Crewe to Dumfries and from Lincoln to Newcastle; and

(*c*) the Scottish zone, extending from the Clyde valley east and north to Dundee, Aberdeen, and Inverness and covering Berwick.

BT is to phase out in these areas the existing operator-based carphone services, which may not continue beyond the end of 1985.

The Automatic Radiphone service will pave the way for the introduction of the new cellular mobile telephone service which BT is planning in partnership with the Securicor Group. This service, which will start in London in 1985, will use much higher radio frequencies working over small areas, or cells.

BT's entry into the mobile equipment market with the introduction of the new Automatic Radiophone service and the telephone in the car service provides BT's customers with a complete package, which is being marketed under the name of *Telecom Emerald* and administered by the BT Spectrum Group; the carphones are being supplied exclusively in Britain by Marconi.

The south-east zone will cover what is expected to be the major market for carphones. BT's customers with automatic carphones in the south-east zone will be able to use their carphones in other Radiophone areas outside of London. If they drive into the London areas they will be able to make, but not receive, calls, because of the lack of allocated frequencies available. This means that customers waiting for the London Radiophone service who join the south-east service can stay on the waiting list for the full London service but enjoy the benefits of the new south-east zone. However, the waiting list for the Radiophone service in London should end after the cellular service gets under way in 1985.

COMPUTERISATION OF INLAND DIRECTORY ENQUIRIES

British Telecom (BT) has awarded Standard Telephones and Cables plc (STC) a contract for an inland computerised directory enquiry system. The new system, known as the *directory assistance system* (DAS), will begin in 1984, and should cover the UK by early 1986.

When completed, the DAS will cut down the handling time for each directory enquiry from approximately 52 s to about 40 s, and will mean that records can be updated more rapidly. In addition, computerisation of directory enquiries will enable Britain's growing number of Prestel users to use their own terminals to call up the DAS to find the telephone numbers they require; eventually, it may be possible for all BT customers with a home or office-based computer terminal to use the system.

The DAS, developed by Computer Consoles Incorporated (CCI) of Rochester, New York, is already in operational use by a number of telephone administrations throughout the world, particularly in the US. The system provides fast access to directory information for trained terminal operators using proven hardware and software. It will be operated 24 hours a day and will have automatic back-up in case of failure.

The DAS database will be held in 3 centres: in the North of England, the Midlands and London, and each will hold replicas of the complete national directory file of 22 million directory entries, which will be updated every 24 hours from BT's main directory system run on ICL 2900 computers. It will also provide facilities for on-line updating of records.

The 4000 operational terminals to be installed at directory enquiry centres throughout the UK will be connected through 9600 bit/s dedicated circuits to one of the 3 DAS centres. If, for any reason, one centre is out of action the terminals will be reconnected to one of the surviving centres. Links between the 3 centres will operate at 48 kbit/s.

The search key for a normal enquiry will consist of the first 3 letters of the name, first letter of street and town, and type of listing. The database will be split into 3 types to speed the system's response: residential, business and government entries—then into geographical segments.

The DAS is designed to handle in excess of 1 million enquiries a day from customers. The operator work station is an ergonomically designed visual display terminal with a simple keyboard and 1920 character display connected to the network through a terminal group controller. Central site equipment will include DEC PDP 1144 processors, the new CCI Power 5 computer, and Control Data disc storage.

Notes and Comments

CONTRIBUTIONS TO THE JOURNAL

Contributions to *British Telecommunications Engineering* are always welcome. In particular, the Board of Editors would like to reaffirm its desire to continue to receive contributions from Regions and Areas, and from those Headquarters departments that are traditionally modest about their work.

Anyone who feels that he or she could contribute an article (short or long) of technical, managerial or general interest to engineers in British Telecom and the Post Office is invited to contact the Managing Editor at the address given below. The editors will always be pleased to give advice and try to arrange for help with the preparation of an article, if needed.

GUIDANCE FOR AUTHORS

Some guiding notes are available to authors to help them prepare manuscripts of *Journal* articles in a way that will assist in securing uniformity of presentation, simplify the work of the *Journal*'s editors, printer and illustrators, and help ensure that author's wishes are easily interpreted. Any author preparing an article is invited to write to the Managing Editor, at the address given below, to obtain a copy.

All contributions to the *Journal* must be typed, *with double spacing between lines*, on one side only of each sheet of paper.

As a guide there are about 750 words to a page, allowing for illustrations, and the average length of an article is about 6 pages, although shorter articles are welcome. Contributions should preferably be illustrated with photographs, diagrams or sketches. Each circuit diagram or sketch should be drawn on a separate sheet of paper; neat sketches are all that is required. Photographs should be clear and sharply focused. Prints should preferably be glossy and should be unmounted, any notes or captions being written on a separate sheet of paper. Good colour prints and slides can be accepted for black-and-white reproduction. Negatives are not required.

It is important that approval for publication is given at organisational level 5 (that is, at General Manager/Regional Controller/BTHQ Head of Division level) and authors should seek approval, through supervising officers if appropriate, before submitting manuscripts.

Contributions should be sent to the Managing Editor, *British Telecommunications Engineering*, IDP 5.1.1. Room 704, Lutyens House, Finsbury Circus, London EC2M 7LY.

CORRECTION

The article entitled *The Sixth International Conference on Computer Communications: A Review*, published in the April 1983 issue of the *Journal*, contains some errors. The name of the Chairman-designate for ICCC '84 in the captions to the photographs on pages 39 and 42 should have been given as Mr. J. H. Curtis, not Mr. J. R. R. Cook as printed. Also, the last paragraph on page 42 should be corrected to read as follows: '... the designated Conference Chairman, Mr. J. H. Curtis, to welcome delegates to Sydney, Australia. Mr. Curtis reviewed the arrangements ...' Mr. J. R. R. Cook is, in fact, the Conference Director for ICCC '84.

The author of the article, Mr. M. B. Williams, and the editors apologise for any embarrassment or inconvenience these errors may have caused.

Forthcoming Conferences

Further details can be obtained from the conferences department of the organising body.

Institution of Electrical Engineers, Savoy Place, London WC2R 0BL. Telephone 01-240 1871

Radio Spectrum Conservation Techniques
6–8 September 1983
University of Birmingham

Advanced Infra-Red Detectors and Systems
24–26 October 1983
Institution of Electrical Engineers

The Impact of High Speed and VLSI Technology on Communication Systems
30 November–2 December 1983
Institution of Electrical Engineers
(Revised information)

Electronic Design Automation (EDA84)
26–30 March 1984
Warwick University

Telecommunications, Radio and Information Technology (Communications 84)
16–18 May 1984
The Birmingham Metropole Hotel
Call for Papers: Synopses by 12 September 1983

European Conference on Electrotechnics—Computers in Communication and Control
26–28 September 1984
Brighton
Call for Papers: Abstracts by 2 December 1983

Institution of Electronic and Radio Engineers, 99 Gower Street, London WC1E 6AZ. Telephone: 01-388 3071

Networks and Electronic Office Systems
26–30 September 1983
University of Reading

FORUM 83 Secretariat, International Telecommunications Union, Place des Nations, CH-1211 Geneve 20, Switzerland.
Telephone: +41-22-995190.

World Telecommunication Forum, Technical Symposium
29 October 1983–1 November 1983
New Exhibition and Conference Centre, Geneva, Switzerland

ISS '84 General Secretariat, Via Aniene, 31, 1-00198 Roma, Italy

International Switching Symposium (ISS '84)
7–11 May 1984
Florence

Conference Clearway Ltd. (United Kingdom Secretariat), Conference House, 9 Pavilion Parade, Brighton BN2 1RA.
Telephone: (0273) 695811/694079.

Teleconference Symposium
3–5 April 1984
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The price to British Telecom and British Post Office staff is 48p per copy.

Back numbers will be supplied if available, price 80p (£1·30 including postage and packaging). At present, copies are available of all issues from April 1974 to date with the exception of the April and October 1975; January, April and October 1976; and January 1982 issues.

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Books of model answers to certain of the City and Guilds of London Institute examinations in telecommunications are published by the Board of Editors. Copies of the syllabi and question papers are not sold by *British Telecommunications Engineering Journal,* but may be purchased from the Sales Department, City and Guilds of London Institute, 76 Portland Place, London W1N 4AA.

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INDEX TO ADVERTISERS

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Alternatively, the panel below, or a photocopy, can be used (only by members) to borrow any book listed in the catalogue or in the updating lists published in recent issues of the *Journal*. The form should be sent to the Librarian at the address above; a self addressed label must be enclosed.

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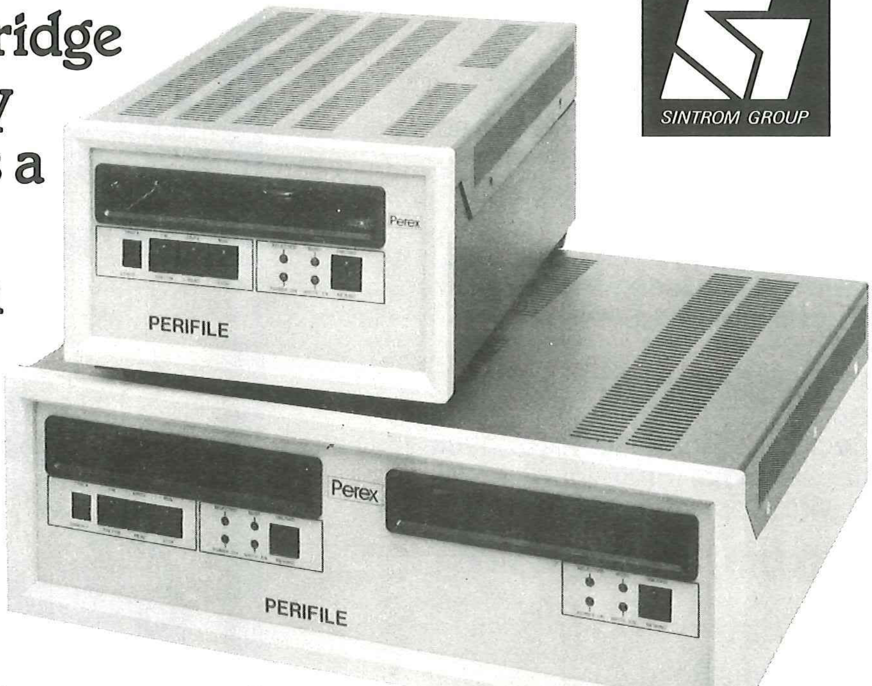

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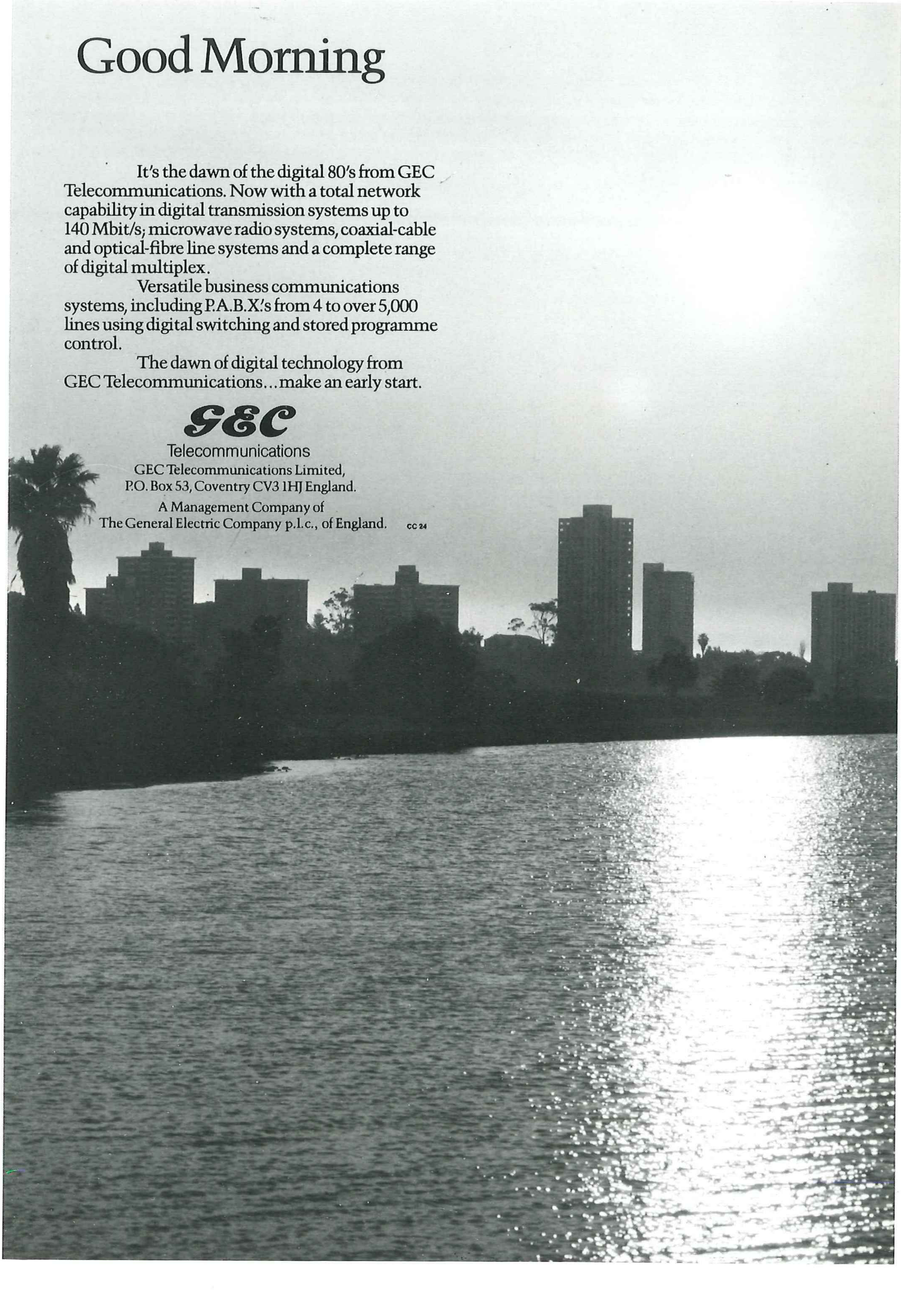
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